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HIGH EXPLOSIVE STORAGE TEST

BIG PAPA

Frederick H. Peterson

Charles J. Lemont
Captain USAF

Robert R. Vergnolle
Lieutenant USAF

TECHNICAL REPORT NO. AFWL-TR-67-132

May 1968

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base
New Mexico

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AFWL-TR-67-132

FOREWORD

This research was performed under Program Element 6.44.15.06.4, Project 3758. Inclusive dates of research were 15 April 1967 to 15 October 1967. The report was submitted 2 April 1968 by the Air Force Weapons Laboratory Project Director, Mr. Frederick H. Peterson (WLDC).

The actual full-scale testing was accomplished between 1 June and 15 October 1967 on the Hill Air Force Test Range located on the west side of the Great Salt Lake approximately 50 air miles west of Hill AFB, Utah. Lt Col Leroy C. Porter was Project Officer for Headquarters USAF (AFRDDC), and Mr. Phil H. Schuyler was Project Officer for the Explosive Safety Branch of the Office of Aerospace Safety, Hq USAF (AFIAS-G2). Photographic coverage of all aspects and Phases of the tests was accomplished by the Air Force Special Weapons Center, Photographic Branch. The Naval Weapons Center, China Lake, California, installed and analyzed the data obtained from the mechanical air pressure gages used in Phases I and II. The project was directed and conducted by the Civil Engineering Branch (WLDC) of the Air Force Weapons Laboratory. Capt Charles J. Lemont (WLDC) was the test Fire Control Officer and was in charge of instrumentation. Lt Robert R. Vergnolle (WLDC) was in charge of construction.

The enthusiastic support of this project by the following individuals and organizations of Hill AFB, Utah, is gratefully acknowledged: Messrs Don E. Burkholder and Glen V. Holley of the OOAMA Plans and Management Office, Mr. Ray Harvey of the Base Civil Engineering Office, Mr. William N. Wale of the Base Procurement office, MSgt Robert L. Davis of the 2701 EOD Squadron, Capt John W. Hunt, the Base Transportation Officer, and Mr. Eugene M. Craner of the Hill Test Range. Acknowledgment is also afforded the USA Corps of Engineers, Waterways Experiment station, Vicksburg, Mississippi, for their assistance in designing and supervising construction of the foam-concrete acceptors used in Phase III of the test. The assistance of Mr. Russel G. Perkins of the Armed Services Explosive Safety Board (OSD) in the planning of this project is also gratefully acknowledged.

This technical report has been reviewed and is approved.

Frederick H. Peterson

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ABSTRACT

(Distribution Limitation Statement No. 4)

In July 1966, the Chief of Staff, USAF, was informed of the critical shortage of munitions storage at air bases in Southeast Asia (SEA). In September 1966, a special Air Force Ad Hoc Study Group was convened at the Armed Services Explosives Safety Board in Washington, DC, to determine if existing munitions storage quantity-distance criteria for barricaded munitions (bombs) could be reduced. The Ad Hoc Study Group recommended a storage configuration incorporating standard earth barricades and reduced quantity-distance criteria which would prevent the propagation of sympathetic simultaneous detonations from one bomb stack to another. The study group also recommended a test program to validate the newly recommended criteria. A four-phase test program was developed and executed as described in detail in this report. Full-scale barricaded bomb stacks were used as donors. Both full-scale and scaled acceptors were used. Donor stacks were detonated to discover if blast, thermal effects, or fragment impingement could produce sympathetic simultaneous detonations in the acceptor stacks. Total explosive weight, distances between stacks of bombs, and types and heights of protective revetments were the basic parameters investigated. No sympathetic simultaneous detonations were propagated from a donor stack to any acceptor in any of the tests. Tests of earth-filled, metal-bin barricades resulted in the conclusion that such barricades should not be used for storage of large quantities of bombs at revised quantity-distance criteria distances.

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ILLUSTRATIONS

ILLUSTRATIONS (cont'd)

ILLUSTRATIONS (cont'd)

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SECTION I

INTRODUCTION

In July 1966 CINCPACAF informed the Chief of Staff, USAF, of problems encountered in stockpiling required munitions (bombs) at Southeast Asia (SEA) air bases in compliance with existing explosives quantity-distance criteria. The problem was caused by the shortage of land upon which the bombs could be stored. The Explosive Safety Branch of the Directorate of Aerospace Safety (AFIAS-G2), Hq USAF, Norton Air Force Base, California, was directed to investigate this critical explosive storage problem. A three-step plan was established.

The first step was the convening, on 7 September 1966, of a USAF Special Study Group by the Chief of the Explosives Safety Branch of the Directorate of Aerospace Safety. This group met at the offices of the Armed Services Explosive Safety Board, Washington, D. C., to research and analyze data on both accidental and planned explosions of large quantities of high explosives to determine if existing quantity-distance criteria could be reduced. The Chief of the Explosive Safety Branch of the Directorate of Aerospace Safety chaired the meeting. Representatives from the Explosive Safety Branch of the Directorate of Aerospace Safety, Pacific Air Force (PACAF), Ogden Air Material Area (OOAMA), and the Air Force Weapons Laboratory (AFWL) comprised the eight-member special study group. Special consultants from the Armed Services Explosive Safety Board (OSD/ASESB) and the US Army Ballistic Research Laboratory (BRL) assisted the group.

The Special Study Group expended approximately eight days (7-15 September) of concentrated effort searching for data and evidence which would identify those parameters pertinent to the propagation of sympathetic simultaneous detonations of adjacent barricaded bomb stacks. The study group soon discovered that very little planned experimentation which was pertinent to the problem at hand had been accomplished. It also become obvious early in the study that high-speed fragments impinging on adjacent stacks of bombs would be the most likely cause of sympathetic simultaneous detonations from one bomb stack to another and that barricades would be necessary to stop these fragments and thereby prevent such propagated detonations.

The conclusions reached by this study group were

a. Properly constructed barricades in conjunction with specified quantity-distance relationships will

(1) Prevent sympathetic detonation between quantities of mass-detonating explosives.

(2) Prevent blast and fragment-induced propagation between quantities of explosives.

b. The current quantity-distance criteria could be revised to increase barricaded storage capacity of munition areas in combat zones.

c. Distances between quantities of explosives could be reduced through proper use of barricades.

d. Based on the study of the available accidental and planned explosive data, the munitions storage criteria established as a result of that effort should be considered for combat zone application.

e. Application of these criteria would increase the storage capacity of combat zone munitions storage areas by a factor of approximately 2-1/2.

f. Testing was required to substantiate this combat zone criteria.

g. Testing was also required to determine optimum barricade geometry for universal quantity-distance application for net weights of mass-detonating explosives in the 125,000- to 500,000-pound range.

Some of the primary recommendations made to the USAF Chief of Staff for approval were

a. A modular concept of munitions storage should be utilized. A module was defined as a barricaded area containing a maximum of five cells separated from one another by an intermediate barricade (see figure 1).

b. The net weight of explosives within each cell would not exceed 100,000 pounds. The distance between the nearest edge of the stacks of bombs in adjacent cells would be a minimum of 50 feet. These distance and weight criteria were based on a K factor of 1.1 in the quantity-distance formula $D = K(W)^{1/3}$ where D is the distance (in feet) between stacks of bombs and W is the net weight (in pounds) of explosive in each stack.

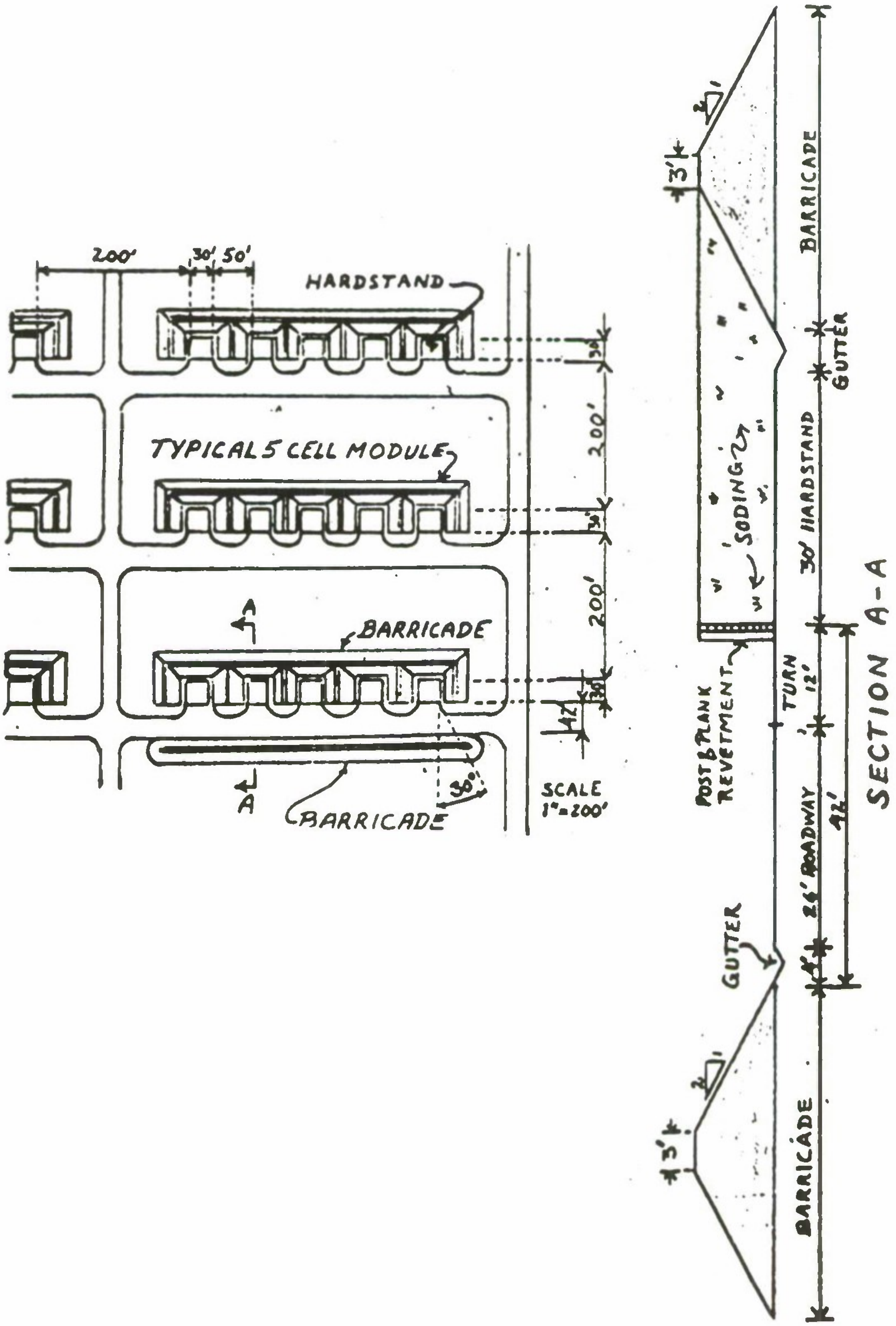

Figure 1. Five-Cell Module Recommended by the Air Force Special Study Group

c. The distance between the nearest edge of stacks of bombs in adjacent modules would not be less than 200 feet. This value was based on a K factor of 2.5 applied to the total net weight* of explosive content of the module.

d. A test program be conducted to develop minimum separation between single stacks of bombs in the 125,000- to 500,000-pound range as it was foreseen that the storage of 100,000 pounds per cell would only temporarily alleviate the problem.

On 27 September 1966, the Vice Chief of Staff, USAF, approved the recommendations of the Special Study Group for immediate use in combat zones.

The second step was a visit to PACAF headquarters by a Munitions Safety Assistance Team in late September 1966 to review combat zone munitions storage areas and collaborate in determining storage solutions on the basis of the criteria developed by the Special Study Group. The need for conducting full-scale field tests employing larger quantities of explosives was confirmed.

Step three consisted of the necessary full-scale field testing. The test was basically required to determine minimum separation between single barricaded aboveground stacks of bombs in the 125,000- to 500,000-pound range and optimum barricade geometry and materials to be used in an explosive storage area. Secondly, testing was required to validate the 100,000-pound modular concept which had been approved for use in combat zones and also to investigate the possibility of using this concept universally.

The initial test planning meeting was held on 8-9 November 1966 at Norton AFB, California, at the request of the Director of Aerospace Safety (AFIAS), Hq USAF, for the purpose of developing a proposed test program. Representatives from AFIAS-G2, AFIIS, AFOCE, AFRST (now AFRDD), AFLC, OOAMA, and AFWL attended this meeting. Technical consultants from the Armed Services Explosives Safety Board (DOD), Chief of Engineers (Army), Ballistics Research Laboratory (Army), and the Naval Ordnance Test Station (now Naval Weapons Center) also attended the meeting. A preliminary test plan and layout for tests resulted. It was agreed that tests should represent standard barricaded field storage conditions for tritonal-loaded bombs (such as the 750-pound M117) with at least six "samples" of acceptors located at

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*All reference to explosive weight signifies net weight of explosives only, exclusive of weight of steel bomb cases.

the same separation formula distance of the approved five-cell module (K = 1.1), or less, from donors containing 250,000 pounds of explosives. The AFOCE representative proposed a barricade comparison test and agreed to provide complete details for constructing a test array of six barricades around a donor of 100,000 pounds of explosives. The proposed test program was approved by the Chief of Staff during the 28 March 1967 staff meetings (Secret letter, AFCCS, 31 March 1967, Minutes of Committee Meetings No. 13 (U)).

The Operational Support Directive (OSD) Number 7-126-(1), dated 5 April 1967, authorized the Project 3758 "Explosive Storage Test," and directed that it be conducted as soon as ordnance was available. On 10 April 1967, AFWL was designated as the agency to direct and conduct the test.

The second planning meeting was held at the Naval Weapons Center, China Lake, California, on 20-21 April 1967. AFWL presented the proposed test plan including an extensive AFWL electronic instrumentation plan. Before this meeting, only three phases of the project had been discussed with test requirements for Phases I and II provided by AFIAS, and AFOCE supplying the requirements for Phase III. Phase IV was proposed at this meeting by the representative of the Air Proving Ground Center (APGC), Eglin Air Force Base, Florida, who also proposed a test procedure.

Final plans and test configurations for the four phases of the test were presented and discussed at the final planning meeting held at Kirtland Air Force Base, New Mexico, on 24 May 1967. Hill Air Force Test Range, Utah, was selected as the test site for the BIG PAPA series.

Revised quantity-distance criteria established within USAF, as a result of this testing, have been included in the latest revision of the USAF "Explosives Safety Manual," AFM 127-100H, dated February 1968.

SECTION II

SCOPE OF TEST

1. TEST OBJECTIVES AND PURPOSE

The primary objectives of the test program were as follows:

a. Determine minimum distance between single stacks of barricaded mass-detonating explosives to prevent simultaneous detonation of adjacent stacks and to minimize nonsimultaneous propagation.

b. Determine the validity of the criteria being used in the 100,000-pound cell (five cells per module) approved for combat zone use by the Vice Chief of Staff, USAF, on 27 September 1966.

d. Determine if the detonation of a single general-purpose bomb, with current explosives fill, within a stack would hurl other bombs into the air above the barricade and subsequently detonate the bombs suspended in the air, resulting in the detonation of adjacent bomb stacks by fragment impingement.

A secondary test objective was to obtain a substantial amount of airblast and ground-shock data for use in future AFWL quantity-distance studies.

The nature of the overall test objectives was such that it was necessary to divide the project into four separate phases. Current criteria applicable to all mass-detonating explosives require that the separation distance (in feet) between aboveground barricaded storage facilities be six times the cube root of the net weight of explosives. This is a K factor of six. Phases I and II were designed to demonstrate the feasibility of reducing these existing explosives quantity-distance criteria to the maximum practical extent for barricaded bomb storage in single stacks in the range of 125,000 to 500,000 pounds of high explosives. Phases I and II were also designed to prove the validity of the five-cell module concept which had just been approved for immediate use in combat zones based on the recommendation of the Special Study Group. The distance between explosives in adjacent cells within the five-cell module was based on a K factor of 1.1 (e.g., 50 feet for 100,000 pounds).

Phase III of this test was designed to determine optimum barricade geometry and materials for use in munitions storage by comparing the fragment attenuating effectiveness of six different barricades. Four vertical-faced metal-bin barricades, a soil-cement barricade, and a standard earth barricade were tested. A secondary objective of this portion of the test was to obtain a multipurpose barricade which could be used for aircraft protection, munitions storage, and for protection of habitable buildings. Metal-bin barricades are not presently being used in combat zones for the storage of large quantities of mass-detonating explosives.

Phase IV was an attempt to determine what would happen when only one bomb in an 80-bomb donor stack was detonated. Two acceptors were placed with center lines 80 feet from the center of a donor. A standard earth barricade separated the donor from the acceptors.

2. DATA ACQUISITION

a. Instrumentation

As previously stated, the secondary objective of this test series was the acquisition of as much data as could be obtained on air pressure and ground motion in the area adjacent to the detonations.

(1) Type of Instrumentation Used

Four types of transducers were used in the BIG PAPA test series. Three of these were electronic transducers which produced parameter-time histories where the parameter was either air pressure, acceleration, or velocity. These transducers were installed, operated, and their data recorded by AFWL. The fourth type of transducer was an electro-mechanical air-pressure gage which was installed, operated, and the data recorded by the Naval Weapons Center, China Lake, California.

b. Fragmentation Survey

Fragmentation surveys were conducted on Phases I, II, and III. All of the survey areas for the three phases were prepared in an identical manner. The areas were stripped of all vegetation and debris, and the ground surface was graded and compacted. All fragments found on these areas after each test were collected, weighed and counted, and the data were tabulated.

(1) Phase I

The fragmentation survey for the Phase I test consisted of establishing two survey lines each extending 5000 feet from the center of the Phase I doner at right angles to each other. Each of these lines consisted of five 300 x 300-foot areas centered at 575 feet, 1890 feet, 3150 feet, 4310 feet and 5000 feet, respectively, from the center of the donor. These distances represent explosives quantity-distance criteria, respectively, as follows: barricaded intraline, barricaded public highway/railway, barricaded inhabited building, and unbarricaded inhabited-building distance for 250,000 pounds of mass-detonating explosives. The area at 5000 feet was added to provide a sample beyond the inhabited-building distance. One of these fragmentation survey lines extended normal to the longitudinal axis of the bombs, and the other extended parallel to the longitudinal axis of the bombs. Figure 2 shows the layout of the fragmentation survey areas.

(2) Phase II

The same fragmentation survey areas that were used in Phase I were reused in Phase II. However, as illustrated in figure 3, the Phase II donor was located 188 feet (center to center of bomb stacks) in front of the original location of the Phase I donor. Therefore, the fragmentation survey areas located on the line that extended parallel to the longitudinal axis of the bombs were not located from the center of the Phase II donor as was the case in Phase I. The direct distances from the center of the Phase II donor to the center of the fragmentation survey areas located on the line extended parallel to the longitudinal axis of the Phase I donor bombs were 605 feet, 1915 feet, 3170 feet, 4320 feet and 5005 feet, respectively. The distances to the fragmentation survey areas located on the line that extended normal to the longitudinal axis of the bombs were then 188 feet greater than those for Phase I.

(3) Phase III

The fragmentation survey for Phase III consisted of establishing two survey lines intersecting at the center of the donor and at right angles to each other. The survey lines extended in four directions, 1850 feet from the center of the donor. Fragment survey areas 100 x 50 feet were centered on each line at 400 feet, 800 feet, 1400 feet and 1850 feet, respectively,

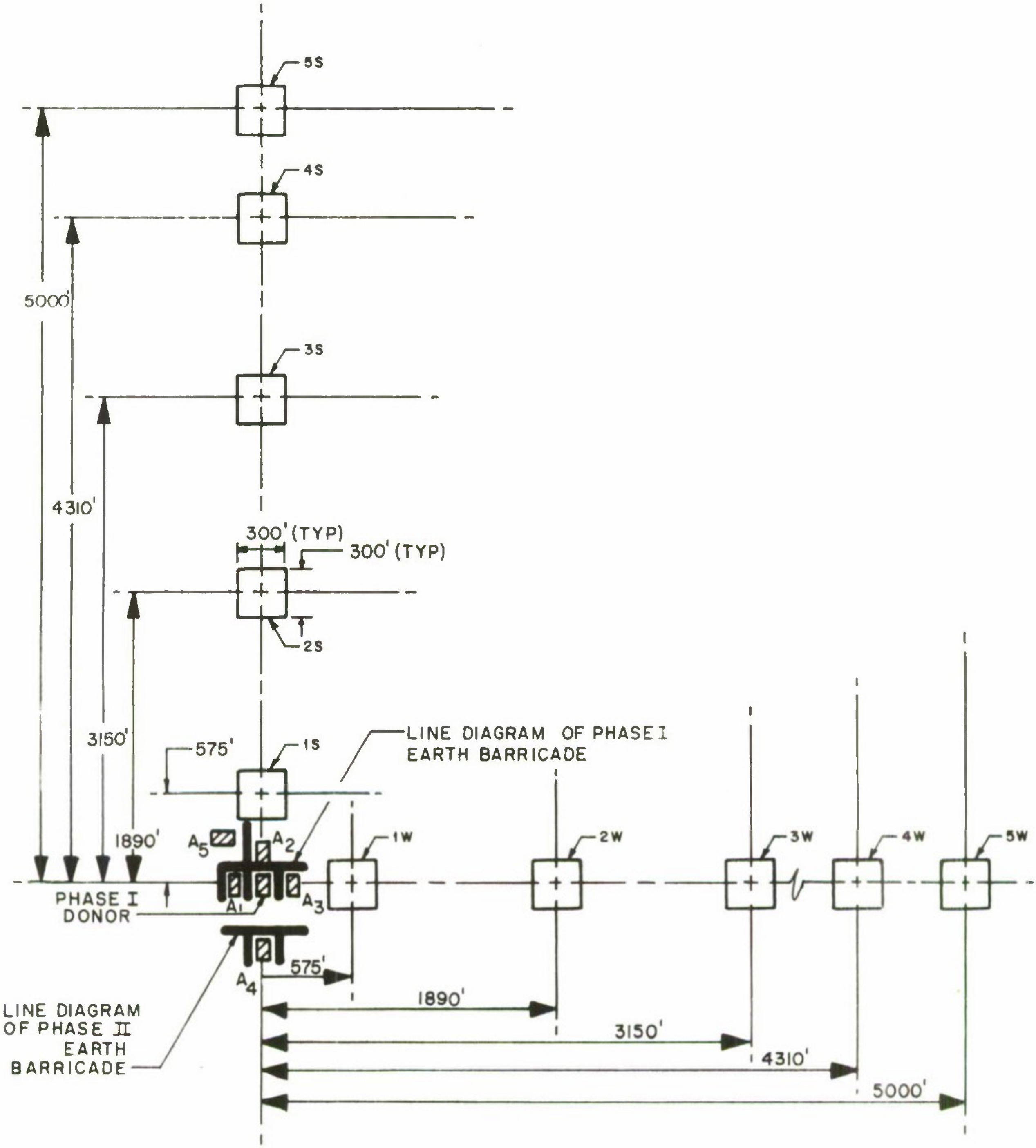


Figure 2. Fragmentation Survey Plan for Phase I

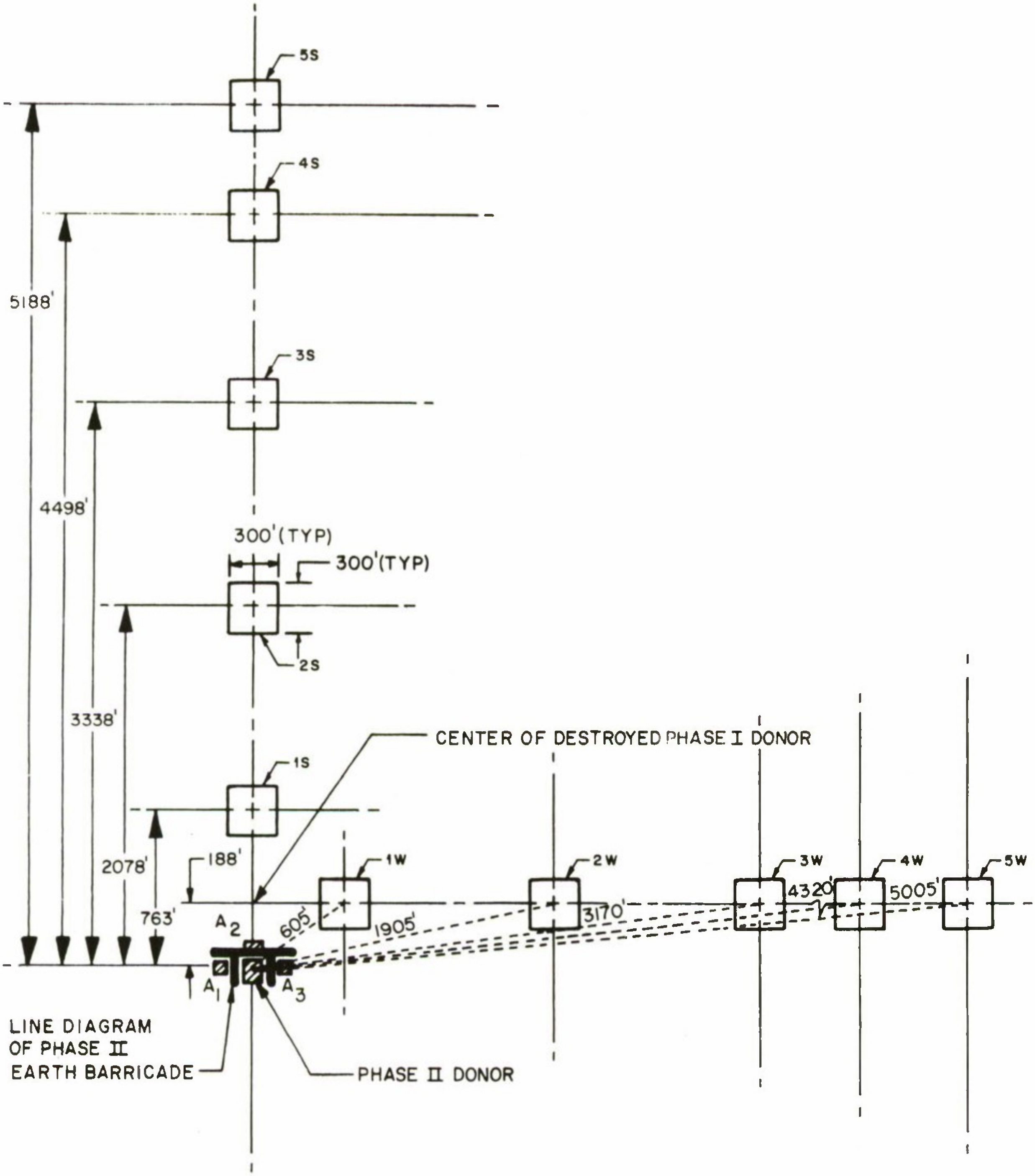


Figure 3. Fragmentation Survey Plan for Phase II

from the center of the donor. This made a total of sixteen fragmentation survey areas. The fragmentation survey plan for Phase III is shown in figure 4.

c. Simulated Aceptors

(1) Preliminary Study

For Phase III, AFOCE proposed the use of foam concrete (also known as cellular concrete) simulated acceptors after a preliminary study had been conducted by the Concrete Division of the Waterways Experiment Station (WES), Jackson, Mississippi. The primary reason for this was that fragment energy data could be obtained and from this, it could be determined whether certain fragments that survived the barricade obstruction would have detonated a bomb stack at the position of the simulated acceptors. Also, this could help in evaluating the fragment attenuating effectiveness of the various barricades.

The preliminary investigation conducted by WES consisted of a laboratory study to show the fragment penetration characteristics of foam concrete and to demonstrate that depth of fragment penetration versus fragment energy could be calibrated. These tests consisted of impacting a 2-foot cube of foam concrete with a plane-faced cylindrical projectile at velocities of 200, 310, and 380 feet per second. The foam-concrete blocks were unconfined with a semirigid support at the rear surface. The foam concrete used in these tests had a density of 43 pounds per cubic foot and the static compressive strength was 156 psi after nine days of curing.

Figure 5 is a graph of projectile velocity versus depth of penetration for the preliminary study. In addition to the graph data, it was found that a clearly defined path of penetrations into the foam concrete existed, and no cracking or spalling was visible which would interfere with a depth of penetration measurement (see figure 6).

From the results of this test, it was concluded that foam concrete could provide the desired material properties for use as a fragment-catching mechanism. Table I contains a summary of the results for this investigation.

After this preliminary study was completed and it was seen that the depth of penetration of a projectile could be measured in foam concrete, it was decided that some additional laboratory tests should be conducted to

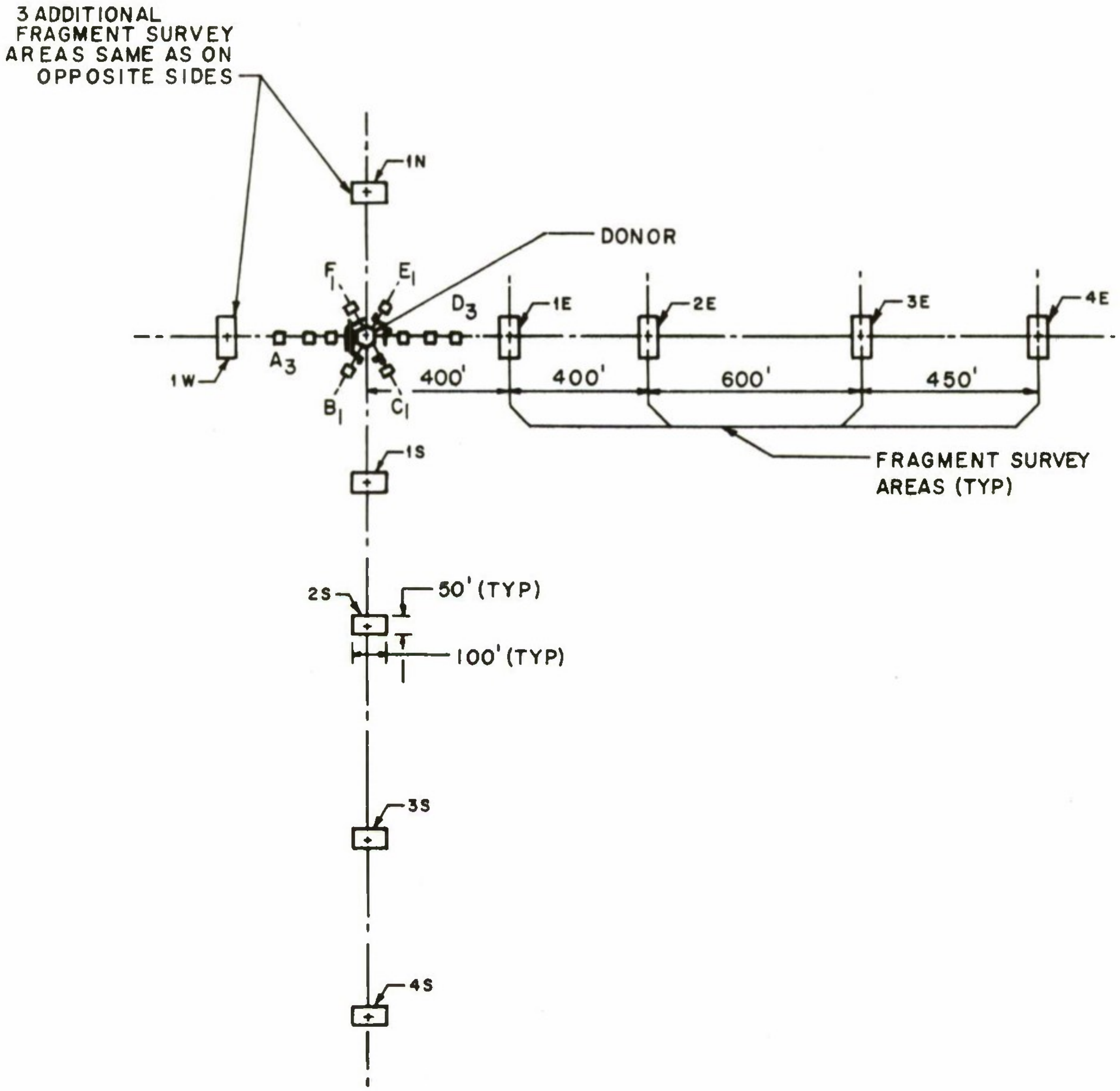


Figure 4. Fragmentation Survey Plan for Phase III

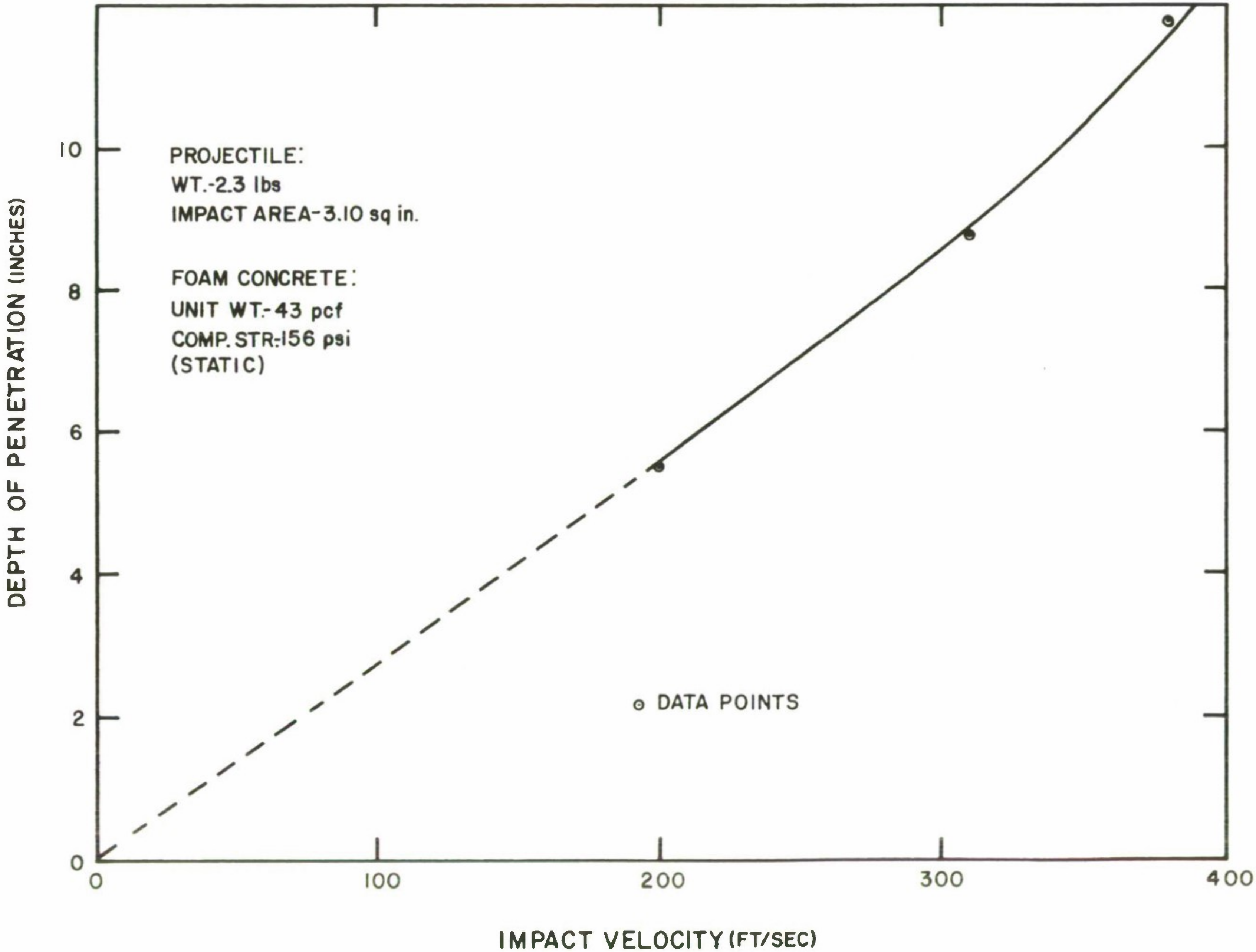


Figure 5. Velocity-Penetration Curve for Laboratory Tests on Foam Concrete

Figure 6a. Round No. 1

Figure 6b. Round No. 2

Figure 6. Penetration of Projectile into Foam-Concrete Laboratory Specimens

Table I

SUMMARY OF FOAM-CONCRETE LABORATORY TEST RESULTS

	Round 1	Round 2	Round 3
Projectile weight (pounds)	2.3	2.3	2.3
Projectile length (inches)	7.5	7.5	7.5
Impact area (square inches)	3.1	3.1	3.1
Impact velocity (fps)	200	310	380
Kinetic energy (ft-lb)	1400	3400	5150
Depth of penetration (inches)	5.5	8.75	11.75

establish a relationship between the depth of penetration and fragment energy. These tests would be performed after the Phase III shot was completed so that the laboratory specimens could be designed to the strength of the field-cured foam-concrete acceptors. It was expected that the most serious factors affecting the validity of these calibration tests would be the irregular shape of the fragments and the determination of the surface areas presented to the foam concrete during penetration. These factors would probably permit only an approximate determination of the impact energy associated with such fragments. WES stated that this problem would exist for any acceptor material used.

For these calibration tests, WES used three shapes of projectiles. each projectile was a plane-faced right-circular cylinder with shaped nose plates; these plates were plane, spherical, and conical. These shapes provided a range of penetration data from which the penetration characteristics of actual fragments could be extrapolated. It was planned to test each of these projectile shapes by using four different velocities.

WES recommended the following mixture for use in constructing the foam concrete simulated acceptors:

Water/cement ratio (by weight)	= 0.65
Density (unhardened)	= 48 pcf
Portland cement, Type III	= 786 lbs/cu yd or 8.36 bags
Water (73°F)	= 511 lbs/cu yd or 61.32 gal
Foaming agent	= less than 0.25 gal/cu yd

The exact amount of foaming agent used depended on the type of foaming agent used, the expansion factor of the foam, and the equipment used by the contractor. WES served as a consultant to the AFWL on-site project engineer on all foam-concrete operations.

(2) Field Layout

Two different shapes of poured-in-place foam-concrete simulated acceptors were employed in Phase III. The first shape, an inverted L (see figure 7) was located directly behind each of the six barricades being tested and at a distance of 50 feet (K = 1.1) from the edge of the 100,000-pound

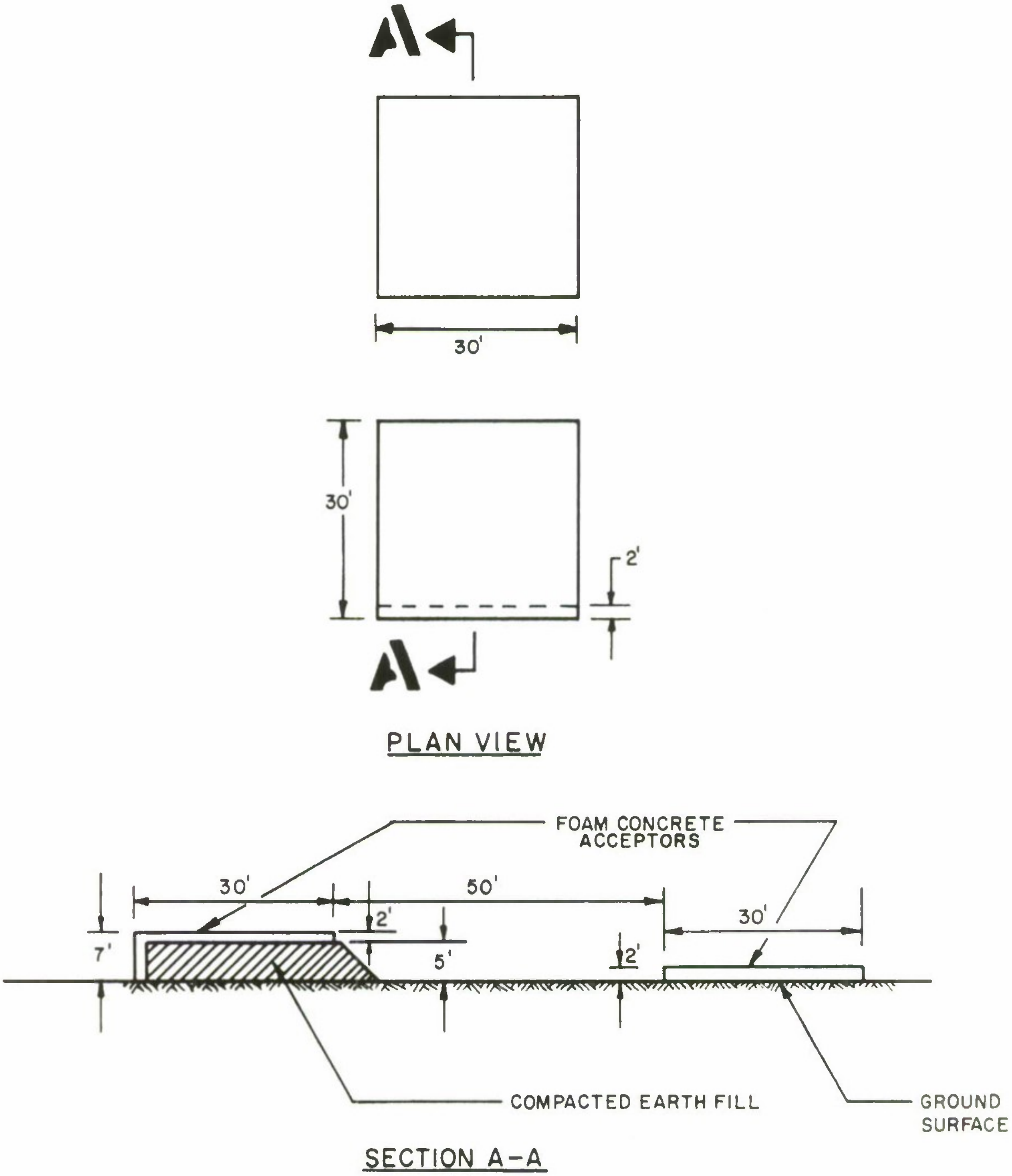


Figure 7. Typical Foam-Concrete Simulated Acceptors

(net weight explosives) donor. These simulated acceptors were constructed on a 5-foot high compacted earth fill. The final surface height was 7 feet, the approximate height of a typical bomb stack.

The second shape (see figure 7) was 30 x 30 feet square by 2 feet thick, and these simulated acceptors were constructed directly on the ground surface. Four such acceptors were constructed on two lines at distances of 145 feet and 225 feet from the donor edge behind Barricades A and D.

(3) Planned Post Shot Activities

After the Phase III shot, WES was to provide an engineer and a technician at the test site to take photographs, plot locations, angles, and depth of penetration, and recover embedded fragments. The fragments were to be returned to the WES laboratory for density and size measurements.

At this time, the laboratory calibration study, which was previously discussed, would be conducted. Graphs, similar to the one illustrated in figure 5, would be developed for each of the three different-shaped projectiles at four velocities. With the depth of penetration of a fragment known, its velocity could be found by using the graph of the projectile most closely resembled by that fragment. With the fragment weight and velocity known, the impingement energy could be computed.

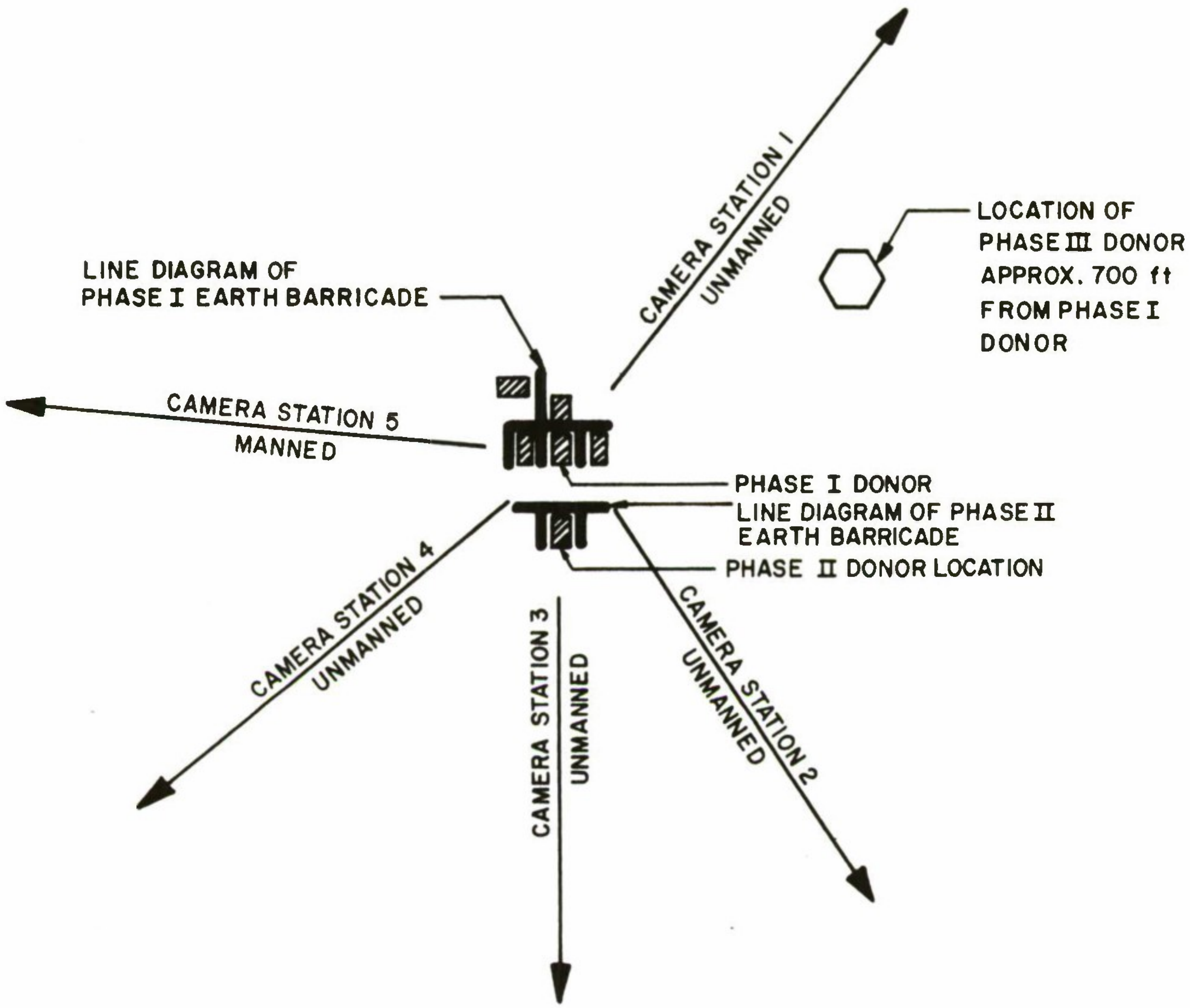
d. Photography

All four phases of the BIG PAPA test series were covered by photography. For Phases I, II, and III, photo coverage was provided from five camera stations surrounding the test site and also by helicopter-borne cameras. The distances from the detonation to the four unmanned camera stations ranged from approximately 1600 feet to 3200 feet. The manned camera station (station number 5) was located on top of a mountain, approximately 1000 feet above the test site and 6000 feet from the detonation. Stations 2, (see figure 8) 3, and 4 were located on relatively high terrain while station 1 (see figure 9) was on top of a 35-foot tower, thus providing excellent coverage of the entire site. Figure 10 shows the photographic layout for Phases I, II, and III.

Phase IV photographic coverage was obtained in a similar manner except that, because of the location of the test site, an additional camera station, also located on high ground, was introduced (station number 6). The distances

Figure 8. View of Phase I from Camera Station Number 2

Figure 9. View of Camera Station Number 1



NOTES: THE SAME CAMERA STATIONS WERE USED FOR PHASES I, II, AND III. PHASE II AND III ACCEPTORS ARE NOT SHOWN.

Figure 10. Photographic Layout for Phases I, II and III

from the detonation to the four unmanned camera stations were approximately the same as for Phases I, II and III. The manned camera station was located approximately 7000 feet from the Phase IV detonation.

The photographic layout for Phase IV is illustrated in figure 11. Tables II, III, IV, and V list the type of camera, frame rate, type of film, and frame size which were used at each station.

All cameras at stations 1, 2, 3, 4, and 6 were started by an electrical pulse from the AFWL instrumentation recording and control van. These electrical pulses were transmitted at two predetermined times, 2 seconds and 1 second before test detonation. In the case of station 5 and in the helicopter, the cameras were started manually at various stages of the last 10 seconds of the countdown.

3. EXPLOSIVES

The explosives used for the four phases of this test were tritonal-filled M66A2 and M117 bombs. Each M66A2 bomb had a gross weight of 2000 pounds. Of this gross weight, 1181 pounds consisted of high-explosive material and the remainder was casing. Each M117 bomb had a gross weight of 750 pounds containing 386 pounds of explosives.

For Phases I and II, two sizes of bomb stacks were used. The 250,000-pound (net weight explosives) bomb stack contained 191 M66A2 bombs and 62 M117 bombs. When completely stacked, the height of the bombs above the top of the concrete pad was about 8 feet 10 inches. This was approximately 2 feet 2 inches below the top of the earth barricade. Each 75,000-pound (net weight explosives) bomb stack contained 55 M66A2 bombs and 26 M117 bombs. These bomb stacks were 6 feet 4-1/2 inches above the top of the concrete pad when stacked. This was 4 feet 7-1/2 inches below the top of the barricade. All the dimensions stated above included the timber dunnage between each layer of bombs. Typical 250,000-pound and 75,000-pound stacks are shown in figures 12 and 13.

Phase III had a hexagonal donor pad constructed about a 30-foot diameter circle. This hexagon was divided into six triangles with each triangle having an identical stack containing 12 M66A2 and eight M117 bombs. This made a total of 72 M66A2 and 48 M117 bombs in the donor stack. This bomb arrangement for Phase III was designed to give each of the six barricades tested an

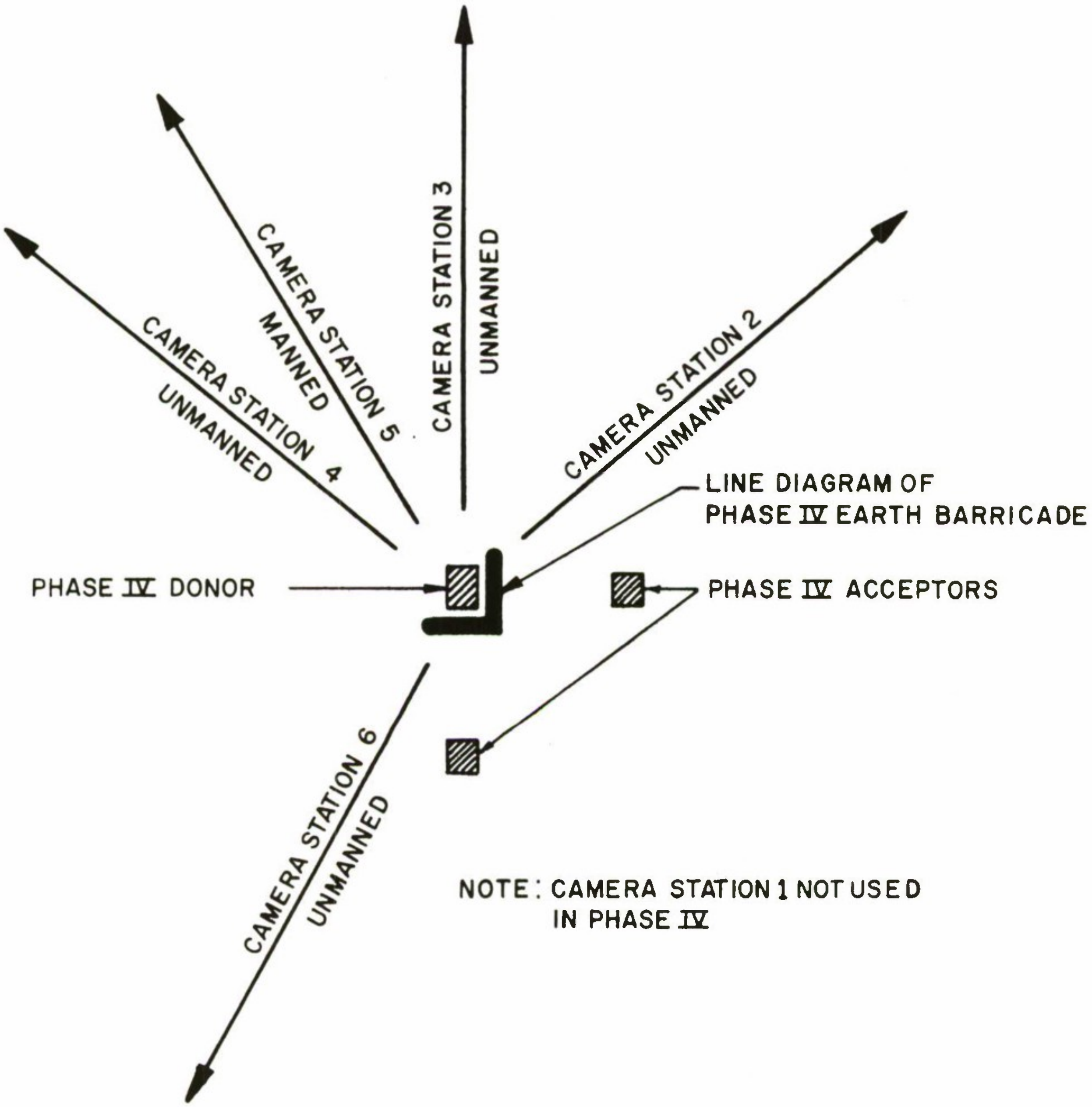


Figure 11. Photographic Layout for Phase IV

Table II

SUMMARY OF PHASE I CAMERA SETUP

Station	Camera	Frame rate (frames per sec)	Type of film (ft)	Frame size (mm)
1	Hycam	3000	Color-EF-400	16
1	Milliken	500	Color-MS-200	16
1	Milliken	500	Color-MS-200	16
2	Hulcher	25	Color-S-100	70
2	Hycam	3000	Color-EF-400	16
2	Fastax	3000	Color-EF-400	16
2	Milliken	400	Color-MS-200	16
2	Milliken	400	Color-MS-200	16
3	---	---	---	---
4	Hycam	3000	Color-EF-400	16
4	Milliken	500	Color-MS-200	16
4	Milliken	500	Color-MS-200	16
5	Hulcher	25	Color-S-100	70
5	Hycam	3000	Color-EF-400	16
5	Milliken	400	Color-MS-400	16
5	Milliken	400	Color-MS-400	16
5	Milliken	400	Color-MS-400	16
5	Milliken	400	Color-MS-400	16
5	Bell & Howell	24	Color-ECO-100	16
5	Airiflex	48	Color-ECO-100	16
5	Graflex	1	Color	4x5 in.

Table III

SUMMARY OF PHASE II CAMERA SETUP

Station	Camera	Frame rate (frames per sec)	Type of film (ft)	Frame size (mm)
1	Milliken	500	Color-MS-200	16
1	Milliken	500	Color-MS-200	16
2	Fastax	5000	Color-EF-400	16
2	Milliken	400	Color-MS-200	16
2	Milliken	400	Color-MS-200	16
3	Milliken	400	Color-MS-200	16
4	Hycam	5000	Color-EF-400	16
4	Milliken	500	Color-MS-200	16
4	Milliken	500	Color-MS-200	16
5	Hycam	5000	Color-EF-400	16
5	Milliken	400	Color-MS-200	16
5	Milliken	400	Color-MS-200	16
5	Milliken	400	Color-MS-200	16
5	Milliken	400	Color-MS-200	16
5	Bell & Howell	24	Color-ECO-100	16
5	Airiflex	48	Color-ECO-100	16
5	Graflex	1	Color	4x5 in.

Table IV

SUMMARY OF PHASE III CAMERA SETUP

Station	Camera	Frame rate (frames per sec)	Type of film (ft)	Frame size (mm)
1	Milliken	400	Color-MS-200	16
1	Milliken	400	Color-MS-200	16
2	Fastax	7000	Color-EF-400	16
2	Milliken	400	Color-MS-200	16
3	Milliken	400	Color-MS-200	16
4	Hycam	9000	Color-EF-400	16
4	Milliken	400	Color-MS-200	16
4	Milliken	400	Color-MS-200	16
5	Hycam	9000	Color-EF-400	16
5	Milliken	400	Color-MS-200	16
5	Milliken	400	Color-MS-200	16
5	Milliken	400	Color-MS-200	16
5	Bell & Howell	24	Color-ECO-100	16
5	Airiflex	48	Color-ECO-100	16
5	Graflex	2	Color	70

Table V

SUMMARY OF PHASE IV CAMERA SETUP

Station	Camera	Frame rate (frames per sec)	Type of film (ft)	Frame size (mm)
1	---	---	---	---
2	Fastax	7000	Color-EF-400	16
2	Milliken	400	Color-MS-200	16
3	Milliken	400	Color-MS-200	16
4	Fastax	5000	Color-EF-400	16
4	Milliken	500	Color-MS-200	16
4	Milliken	500	Color-MS-200	16
5	Hycam	5000	Color-EF-400	16
5	Milliken	400	Color-MS-200	16
5	Milliken	400	Color-MS-200	16
5	Milliken	400	Color-MS-200	16
5	Milliken	400	Color-MS-200	16
5	Airiflex	48	Color-ECO-100	16
5	Graflex	1	Color	4x5 in.
6	Milliken	400	Color-MS-200	16

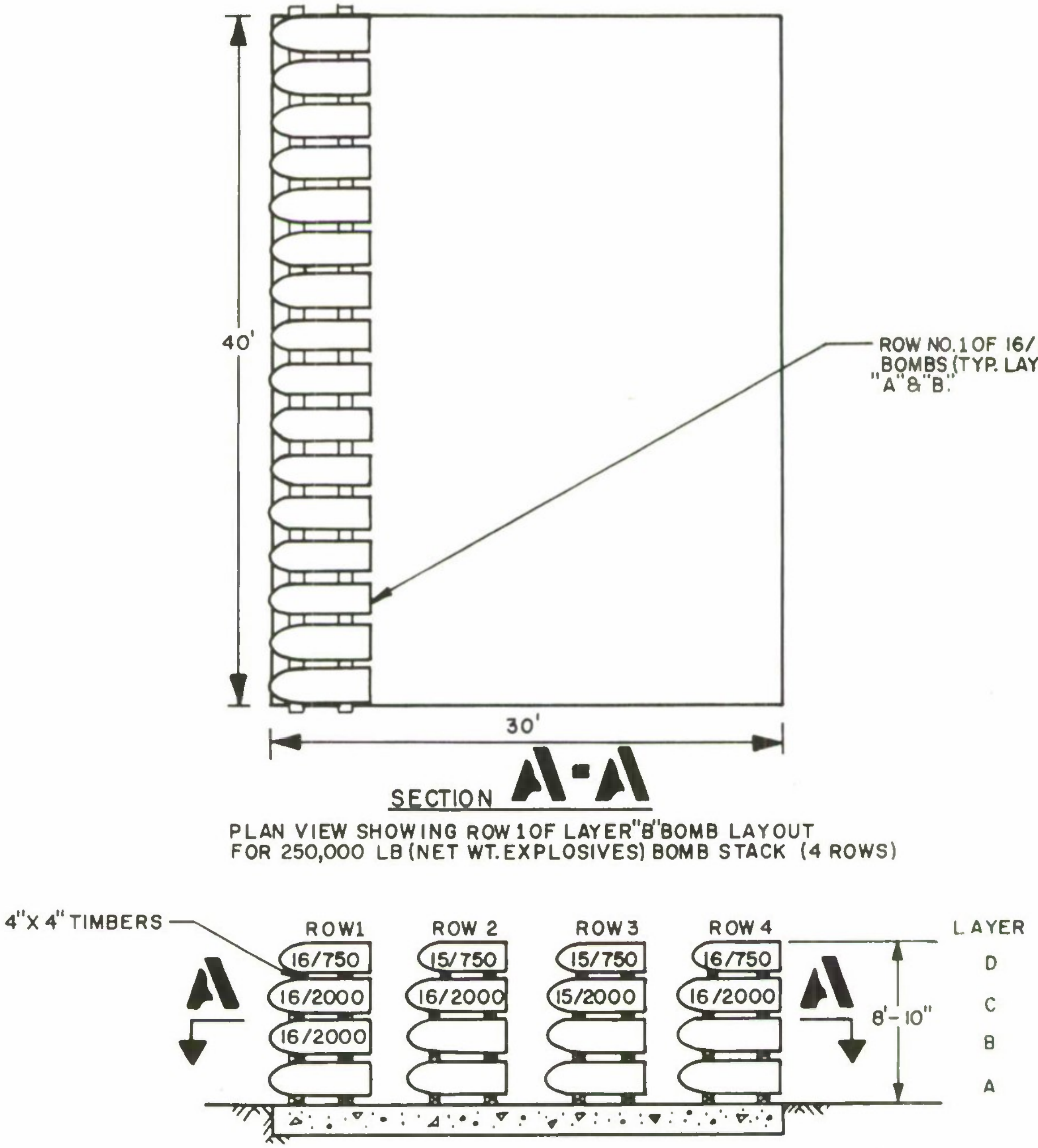


Figure 12. Typical Bomb Arrangement for 250,000-Pound Bomb Stack

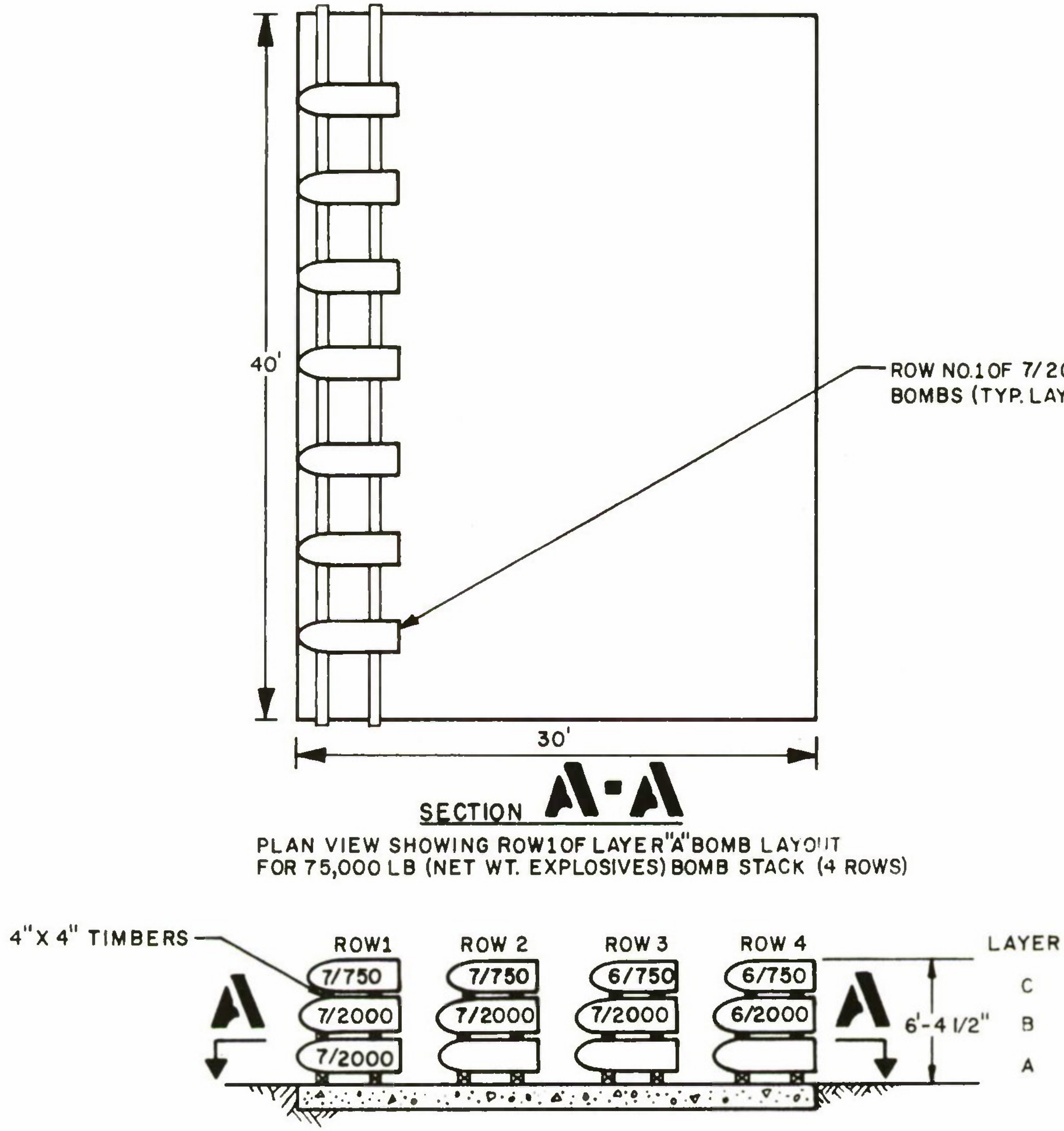


Figure 13. Typical Bomb Arrangement for 75,000-Pound Bomb Stack

equal test environment (fragmentation, airblast, and ground shock). The height of the bomb stack above the top of the concrete pad was approximately 6 feet 6 inches. The bomb arrangement is illustrated in figure 14.

The Phase IV donor consisted of 80 M117 bombs 30,880 pounds (net weight of explosives). The two acceptors were identical with each containing 39 M66A2 bombs 46,060 pounds (net weight of explosives). The bomb arrangement for the donor and for a typical acceptor is shown in figure 15.

The first layer of bombs was stacked on 4 x 4-inch timbers which rested on the concrete storage pad. Additional 4 x 4-inch timbers were placed between the remaining layers of bombs with 2 x 4-inch timbers used as chocks to prevent the bombs from rolling and to maintain proper bomb spacing. This procedure for stacking the bombs was used on all four phases.

All the bombs in the donor stacks in Phases I, II, and III were primed and simultaneously detonated. In Phase IV, only one bomb (figure 16) in the donor stack was primed.

4. TEST CONTROL AND FIRING

Because of the safety requirement that personnel be evacuated a minimum distance of 2 miles, remote operation of the recording van was required. The hardened section of the van containing the recording and control equipment was located approximately 700 feet from the Phase I and Phase II shot location and covered with 5 feet of earth. Control cables were laid to a bunker which was used as the master control area. At the master control bunker, the Fire Control Officer (FCO) monitored the WWV (call sign for worldwide timing network) time being registered in the van, monitored the start of magnetic tape recorders, and could have stopped the test at any time up to the actual firing.

The recording equipment was prepared and the time code generator was synchronized with the WWV time. This time synchronization allowed other interested agencies to know exactly when the test was fired by reference to a common time base. A time programmer was set up so that instrumentation and recording functions could be automatically started at preselected times. One of these programmed functions was the actual initiation of the detonation of each test. Only by a decision of the FCO to hold the test and the actual closure of the hold switch could the programmed times pass without the activity

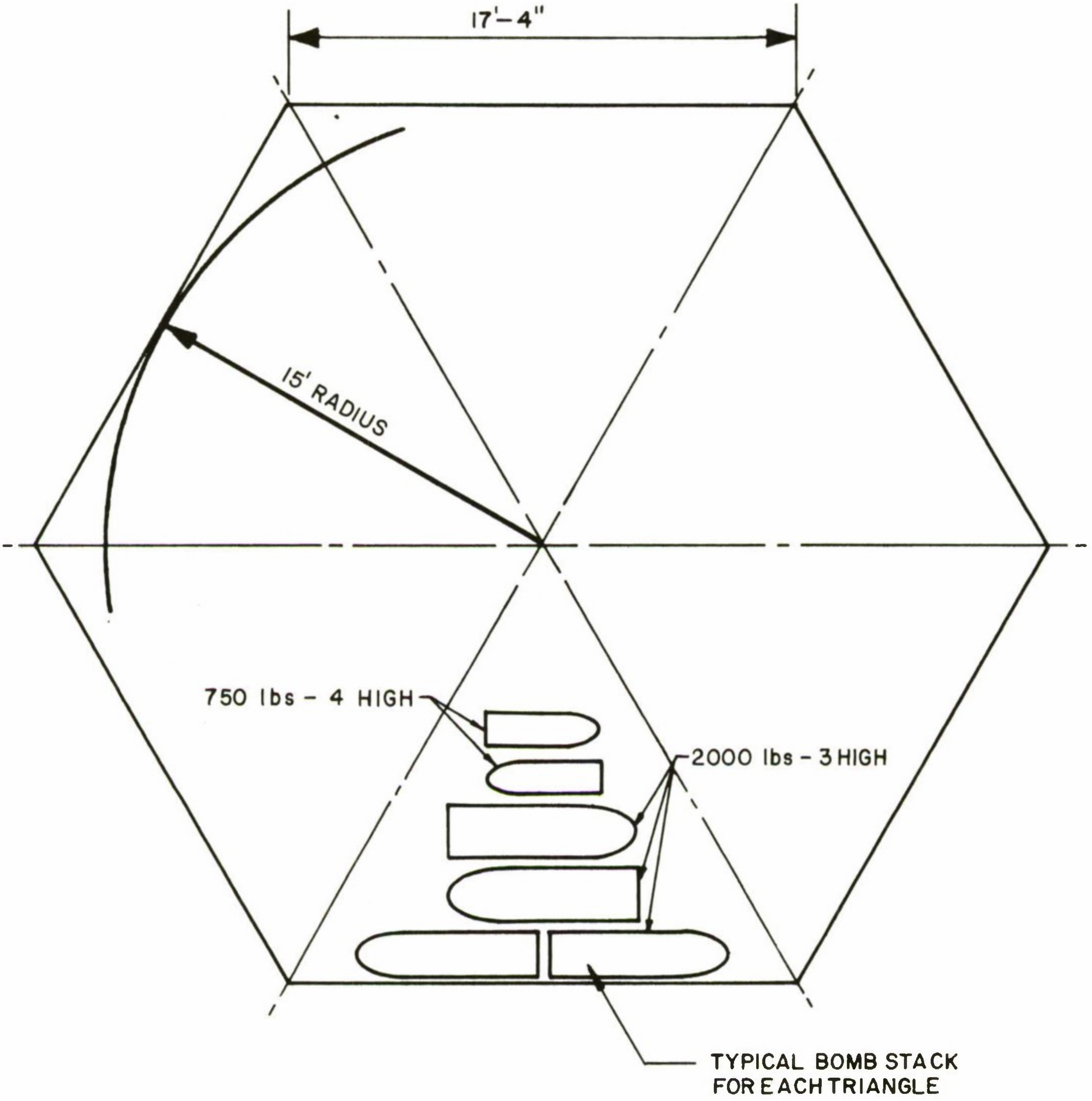


Figure 14. Phase III Bomb Stack Configuration

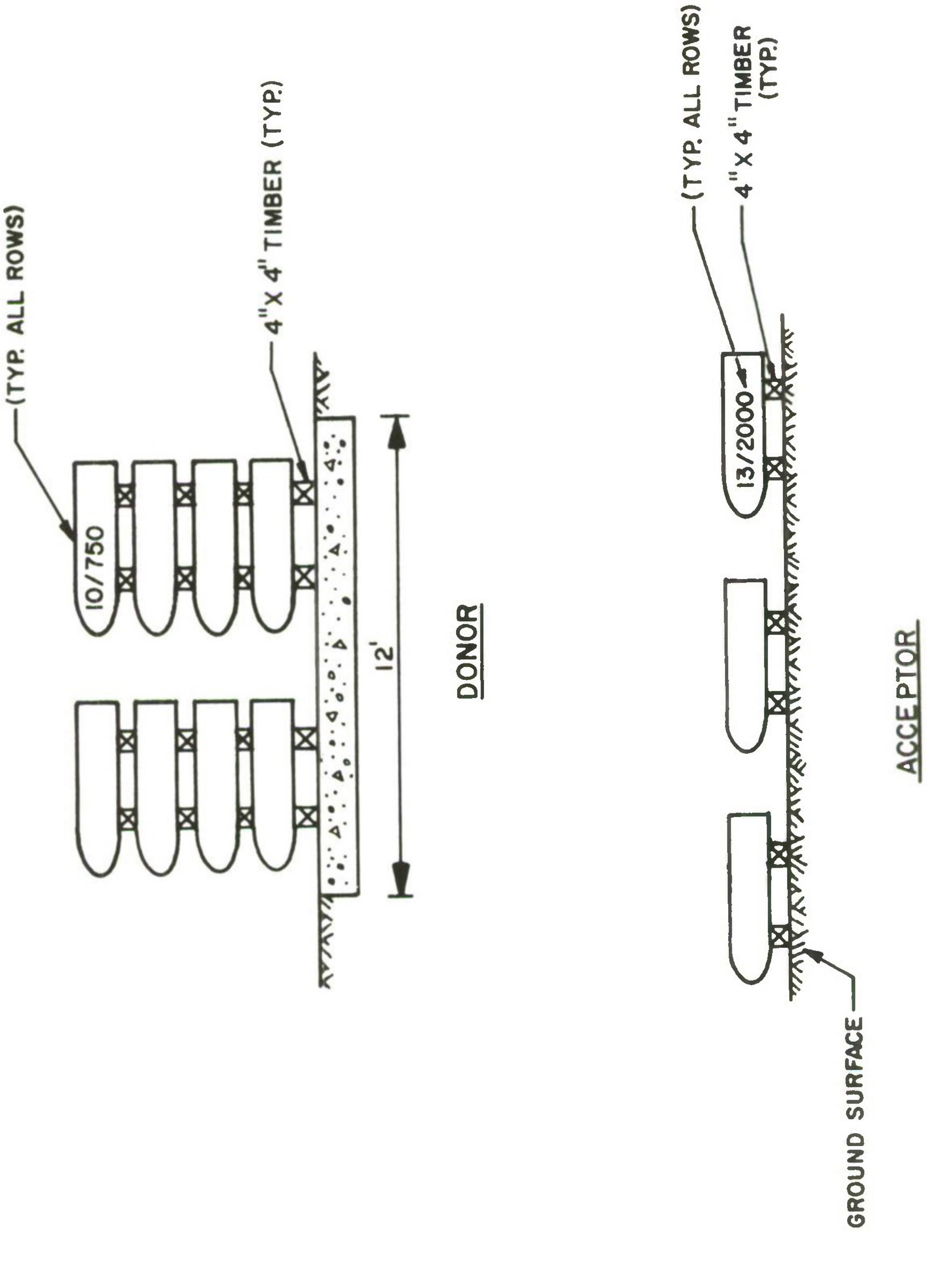


Figure 15. Cross Section of Phase IV Donor and a Typical Acceptor

occurring. If such a hold condition were to become necessary, the FCO would have had the option of waiting 1 hour until the programed times recurred. Or a crew could have been dispatched into the recording van area to reprogram the activities to occur at later times within the same hour.

Figure 16. Phase IV Donor Stack Showing the Single Primed Bomb

SECTION III

PHASES I AND II

1. GENERAL

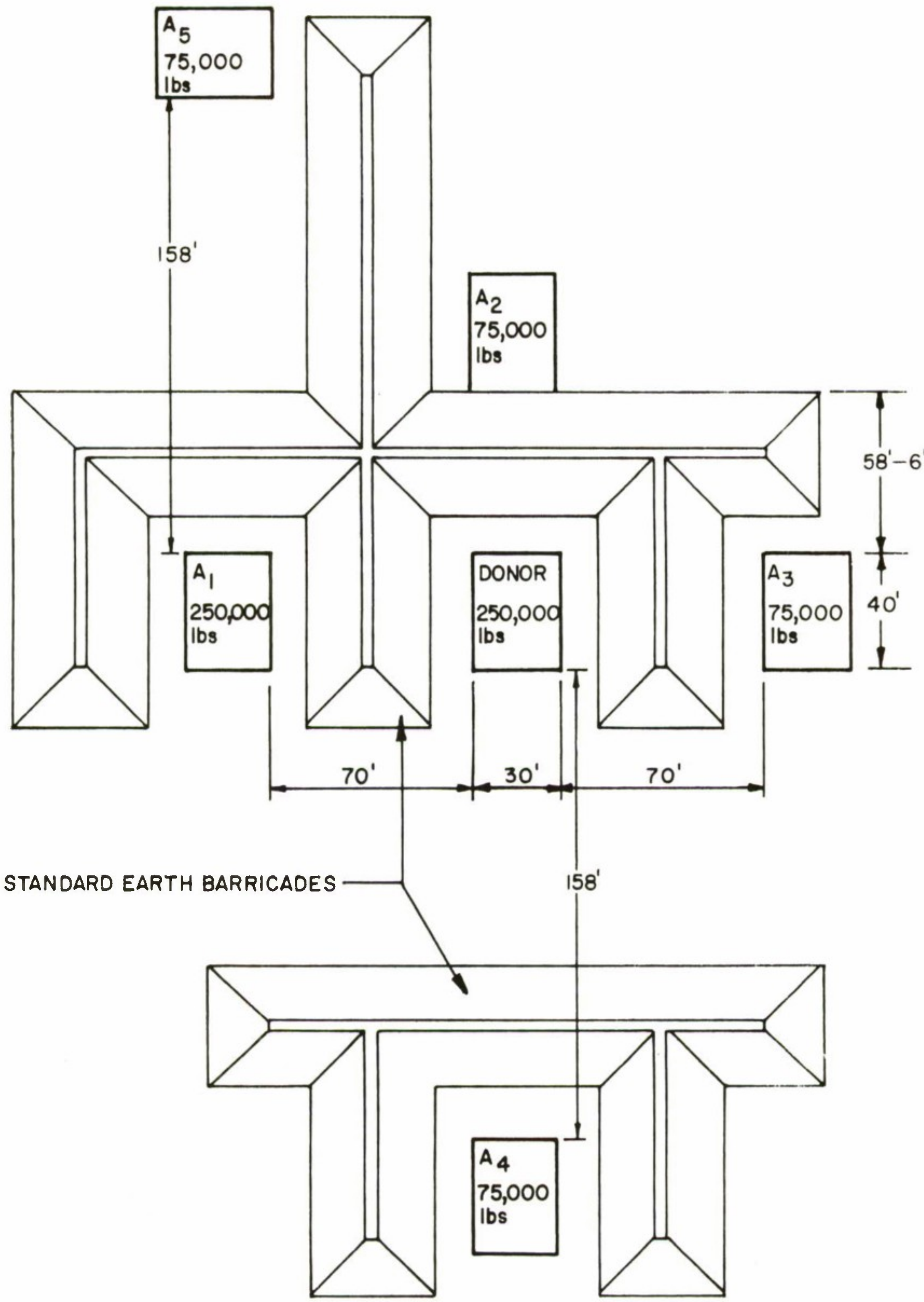
Phases I and II of Project BIG PAPA had identical objectives. Phase II was essentially a repeat of Phase I except that only three acceptors were used instead of five. The Phase I shot was fired at 1000 hours (MDT) on 26 July 1967, and Phase II was fired at the same hour on 30 August 1967. These two phases provided four "samples" of acceptors located at K-factor distances of 1.1, one at a K-factor distance of 0.9, one at 0.8, and two at K-factor distances of 2.5.

2. DESCRIPTION OF PHASE I

A layout of Phase I is shown in figure 17. This portion of the test consisted of a 250,000-pound donor, a 250,000-pound acceptor, and four 75,000-pound acceptors all separated by standard earth barricades. The large acceptor, A1, was separated from the donor by a distance of 70 feet representing a K factor of 1.1. Acceptors A2 and A3 were separated from the donor by distances of 58 feet 6 inches and 70 feet representing K factors of 0.9 and 1.1, respectively. Acceptor A4 was separated from the donor by a distance of 158 feet representing a K factor of 2.5 while A5 was located the same distance from A1. The donor and all acceptors, with the exception of acceptor A5, were placed on reinforced-concrete slabs 30 feet wide by 40 feet long and 9 inches thick. One-half-inch diameter steel reinforcing bars were placed 3 inches from the top of each slab and spaced 18 inches center to center in both directions. The tops of the donor and acceptor A1 stacks were approximately 8 feet 10 inches above the tops of the concrete pads, and the tops of the barricades were 11 feet above the concrete pads.

3. DESCRIPTION OF PHASE II

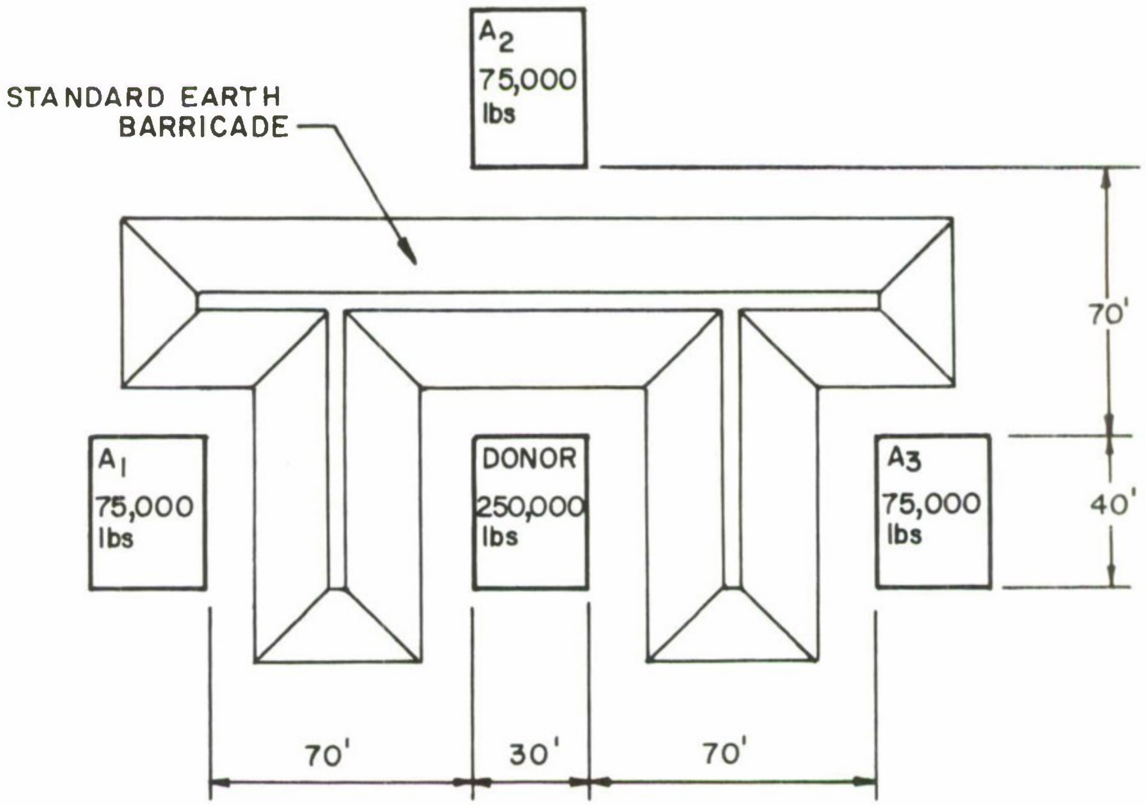
During the planning stages of the test, the Phase II layout was based on predicted results of Phase I. Phase II, as originally planned, was to consist of a 250,000-pound donor and three 75,000-pound acceptors with all



NOTES: DONOR, A_1, A_2, A_3 AND A_4 ARE ON REINFORCED CONCRETE. A_5 IS ON THE NATURAL GROUND SURFACE. ALL WEIGHTS ARE NET WT EXPLOSIVES.

Figure 17. Test Configuration for Phase I

acceptors spaced 70 feet from the donor (K factor of 1.1). The three acceptors and the donor were to be separated by standard earth barricades as shown in figure 41. The donor was to be placed on a concrete storage pad, whereas the three acceptors were to be placed on timber dunnage directly on the ground surface. The original Phase II layout is shown in figure 18. The final design of the Phase II test was based on results of the Phase I test.

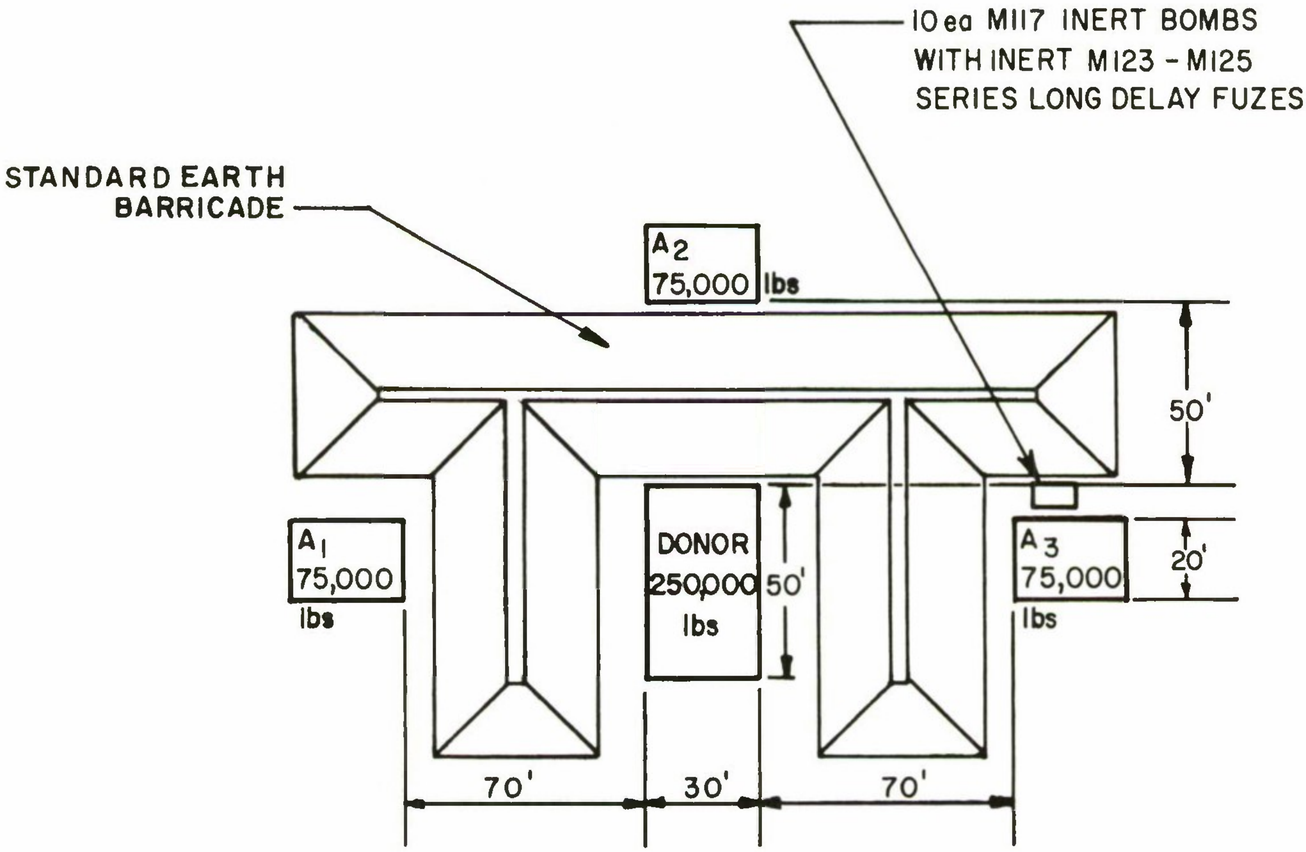


NOTE: Donor is on reinforced concrete. A1, A2, and A3 are on natural ground surface. All weights are net weight explosives.

Figure 18. Originally Planned Test Configuration for Phase II

After the Phase I shot, the Phase II test layout was modified to test one acceptor at a K-factor distance of 0.8 (50 feet for 250,000 pounds). This was done in an attempt to find a lower limit K factor for the 250,000-pound detonation. If the acceptor located at a K-factor distance of 1.1 survived and that at factor 0.8 did not, it would be reasonable to assume that the K factor of

1.1 was the minimum safe factor to use. Should the acceptor at a distance corresponding to a K factor of 0.8 survive, it would increase the confidence in the validity of the K factor of 1.1. Also, it could possibly lead to a study concerning the feasibility of raising the present 100,000-pound limit per cell for the five-cell module to 250,000 pounds per cell. This would increase the capacity of this module by a factor of 2.5. The acceptor distance selected for modification in Phase II was that for acceptor A2. Another change incorporated into Phase II was the use of reinforced-concrete storage pads under acceptors A2 and A3 rather than the natural ground surface. Acceptor A1 was retained on the natural ground surface as originally planned. A diagram and photograph illustrating the revised Phase II test arrangement are shown in figures 19 and 20.



NOTE: Donors A2 and A3 are on reinforced concrete. A1 is on the natural ground surface. All weights are net weight explosives.

Figure 19. Test Configuration for Phase II

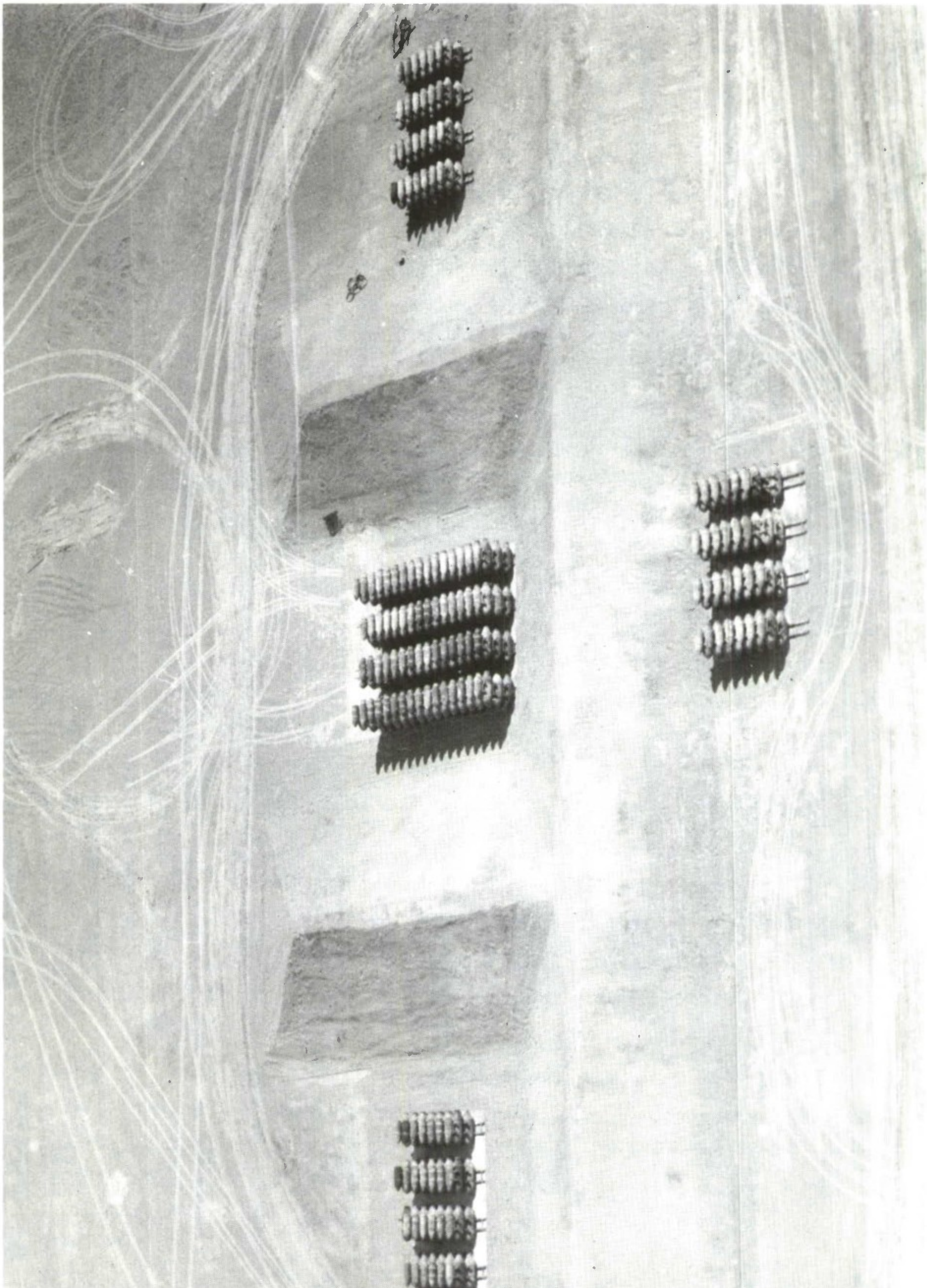


Figure 20. Aerial View of Phase II Test Configuration

Ten M117 bomb bodies loaded with sand and assembled with fins and inert long-delay fuzes of the M123-M125 series were located in the A3 acceptor site of Phase II between the A3 acceptor bombs and the back barricade as shown in figure 19. Bombs were oriented side on to the donor and stacked four high in a pyramid of 4, 3, 2, and 1. Wooden dunnage was used on the ground and between each layer of bombs. The purpose of this was to determine the effect of the donor explosion on assembled (ready) bombs with these fuzes. The ampoules in all of these fuzes were intact before the donor explosion.

4. CONSTRUCTION PROCEDURES

a. Instrumentation Placement

Three operations were involved in the placement of the instrumentation: the preparation and burial of the data-transmission cables, preparation and installation of the air-pressure transducers, and preparation and installation of the accelerometers and velocity transducers.

(1) Data-Transmission Cable

Approximately 1650 linear feet of 2-foot wide trench was excavated by backhoe for the placement of the data-transmission cable. Trenches extended to all points where transducers were located. In the immediate vicinity of the earth barricades, the trenches were excavated to a depth of 8 feet. Trenches farther from the detonation area, where lower stress and shock levels were expected, were 5 feet deep. All trenches outside a radius of approximately 400 feet from the detonation were 2 feet deep. These shallow trenches carried cables to the transducers on the extended instrumentation line and into the recording van. All 5- and 8-foot deep trenches had 1 foot of loose excavated material placed in the bottom to act as a cushion for the data-transmission cables.

In conjunction with the trench excavation, a 10 x 25-foot excavation 6 feet deep was prepared into which the recording and control van, after being removed from the trailer, was lowered and covered (figure 23) with about 5 feet of loose earth. The data-transmission cable was a three-pair shielded cable* with one pair used to carry the excitation signal to the Wheatstone

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*Belden 8777 cable, manufactured by Belden Co., Chicago, Ill.

bridge in the transducer and a second pair used to carry the transducer output to the amplifier. The third pair independently introduced the calibration resistor across one arm of the bridge to produce the known analog output signal.

A predetermined number of transducers were placed in accordance with the instrumentation plan. An equal number of transmission cables were bundled together and prepared in the following manner: a strip of 1/2-inch thick polyfoam about 6 to 9 inches wide and 6 feet long was used to spiral-wrap each bundle of cables such that a double thickness of the material covered the entire length of the bundle. Following the polyfoam wrapping, the entire length of each bundle was spiral-wrapped with cloth-backed tape. When the entire wrapping and taping operation was completed, each bundle was slipped into a plastic irrigation pipe of appropriate inside diameter to allow space for movement. The entire assembly was then buried in the trench. The extensive effort at cable protection was to prevent spurious signals from being introduced into the cables by detonation shock. Such signals would probably be superimposed on some of the data recordings.

(2) Air-Pressure Transducers

After all the data-transmission cables were placed, the air-pressure transducer placement began. To properly anchor the transducer in the desired location, a concrete block 12 inches square and 18 inches deep was built, which contained a transducer receptacle and cable inlet tube (figure 21). This block was placed such that the transducer-bearing surface was coincident with the ground surface. The data-transmission cable was connected to the transducer and the transducer was bolted into place with the diaphragm in the plane of the ground surface. This transducer was then ready for field calibration.

One of the objectives of this test was to determine the effect of airblast pressure on stacks of explosives. It was decided to measure the frontal pressure at approximately one-half the height of a stack. Therefore, special transducer-mount boxes were designed and placed on top of 5-inch diameter 9-foot long steel posts. Each post was buried one-half its length after the data-transmission cable had been threaded through it. The transducer was then connected to the cable and bolted into place in preparation for field calibration.

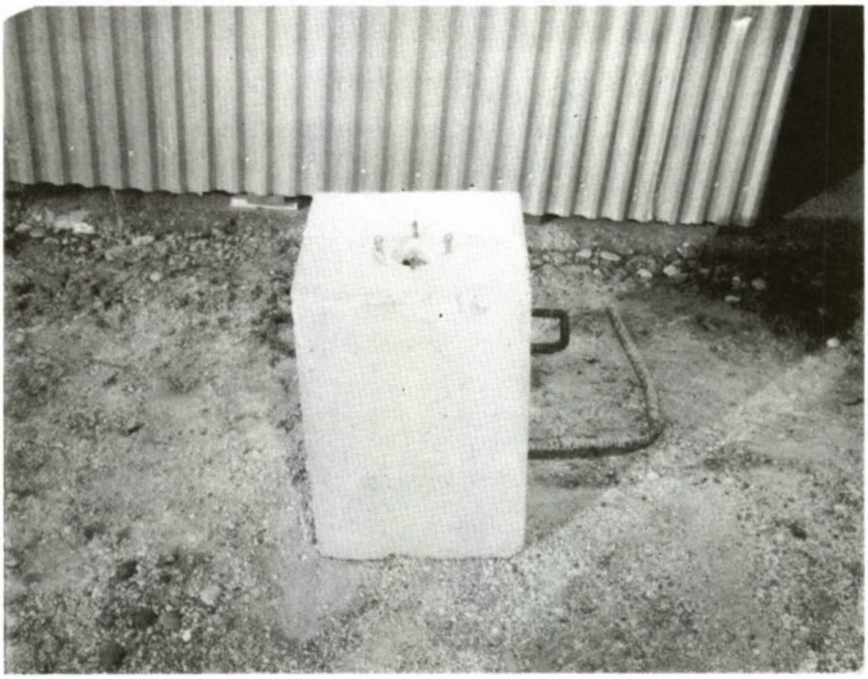


Figure 21. Surface Air-Pressure Transducer Mount

(3) Velocity and Acceleration Transducers

Velocity transducers were used only in Phase I of the test series. In that particular phase, the motion of the barricade between the donor and acceptor Al was to be studied in detail in an effort to better understand barricade design requirements. Velocity transducers had been found to produce the most reliable data and were used alternately with accelerometers in the barricade motion study.

Before barricade construction was started, an 8-inch diameter hole was drilled at a point directly between the donor and acceptor Al, and directly under the centroid of the barricade. At the 20-foot depth, a vertical and a horizontal accelerometer were placed. The hole was then backfilled with excavated material to a depth of 10 feet where vertical and horizontal velocity transducers were placed. The hole was then backfilled to a depth of 5 feet where a second pair of accelerometers was installed. The hole was then backfilled to the original ground surface where a second pair of velocity transducers was placed. As the construction of the barricade proceeded, pairs of accelerometers were installed at 3 feet and 9 feet above the ground level and a pair of velocity transducers at 6 feet. An additional pair of accelerometers

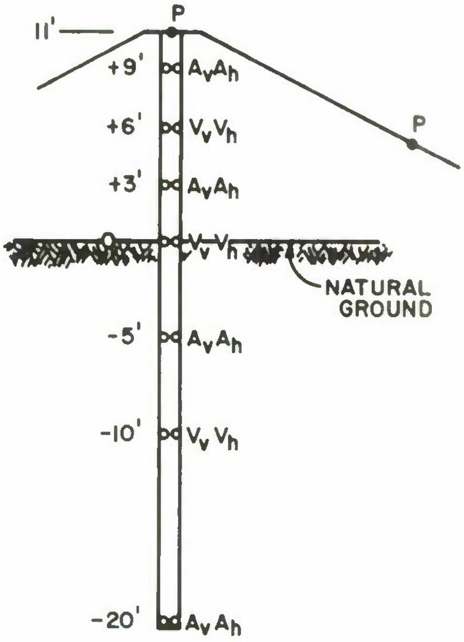
was installed half way up the sloping face of the barricade near acceptor A1. Figure 22 shows a section through this subsurface instrumentation.

A_v = accelerometer (vertical)

A_h = accelerometer (horizontal)

V_v = velocity (vertical)

V_h = velocity (horizontal)



SECTION "A"

Scale: 1" = 10'

Figure 22. Instrumentation Layout for Barricade Response and Subsurface Measurements

In addition to the instrumentation placed to measure the response of the barricade, two pairs of accelerometers were located in the concrete storage pad of acceptor A1 and two vertical accelerometers were located at selected K factor distances from the donor. The pairs of accelerometers located in the concrete pad in Phase I were placed there for comparison with accelerometers in Phase II which were located under an acceptor resting on the natural ground surface and at the same K factor distance from the donor. The instrumentation layout for Phase I is shown in figure 23 and that for Phase II is shown in figure 24.

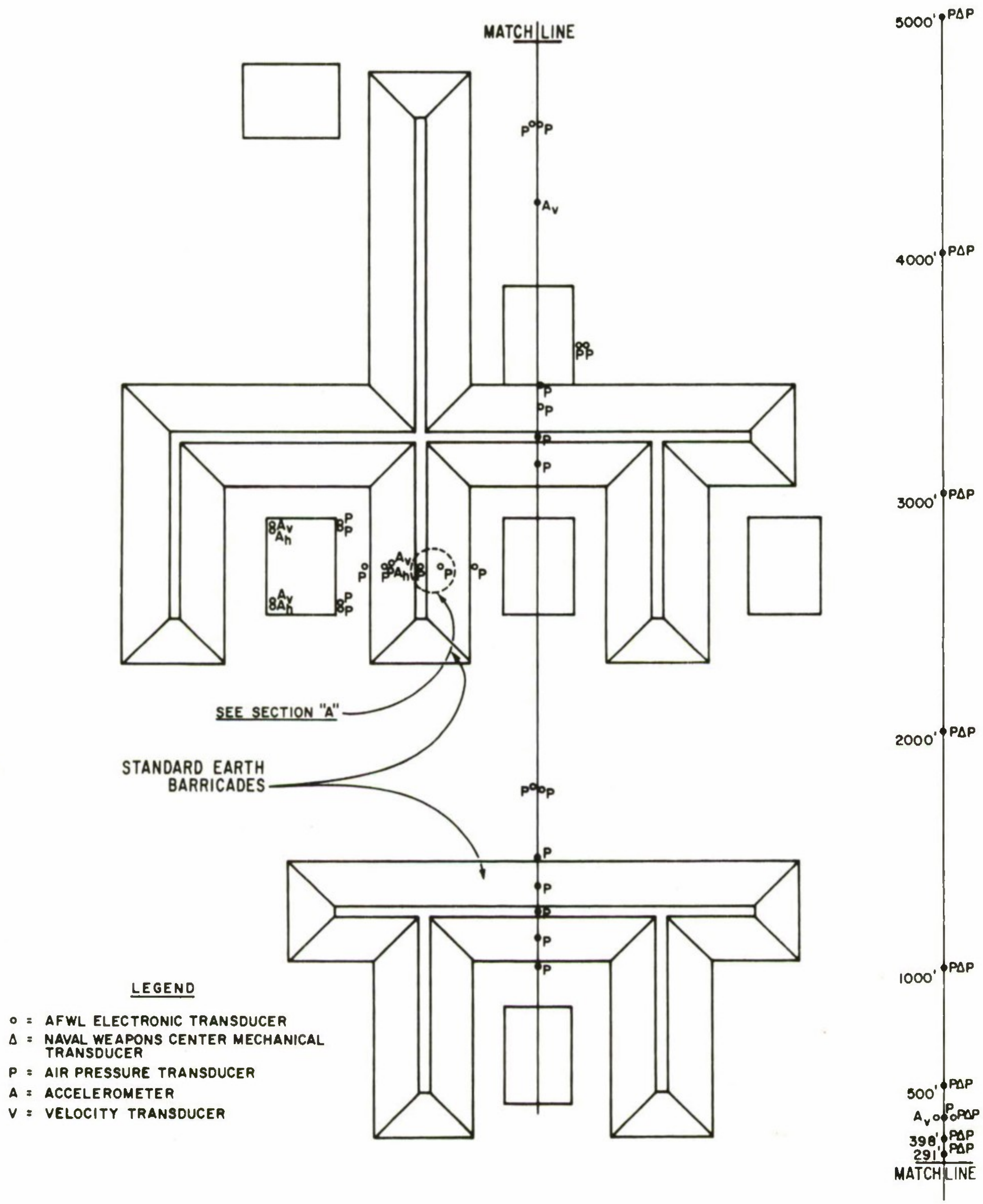


Figure 23. Phase I Instrumentation Layout

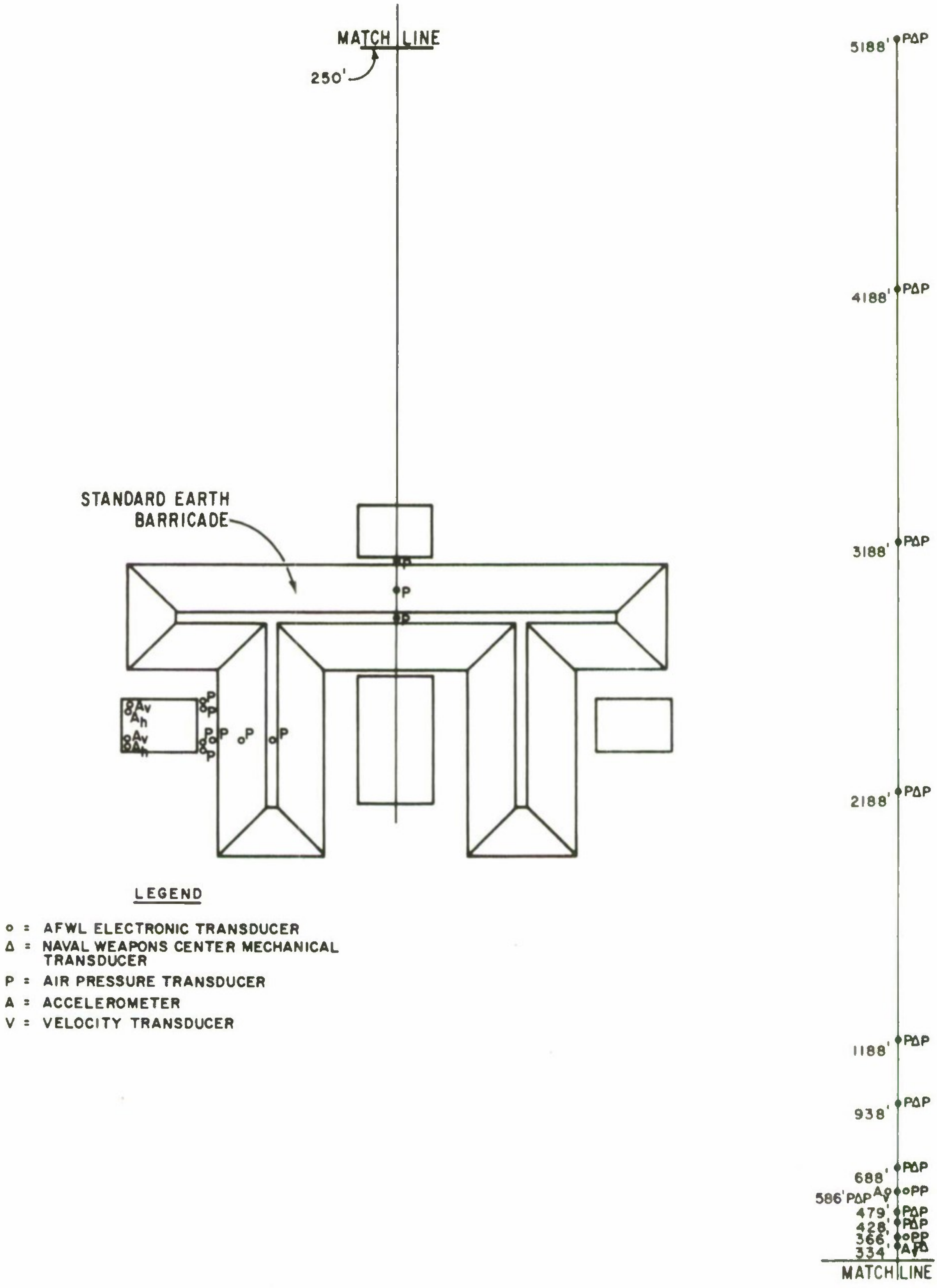


Figure 24. Phase II Instrumentation Layout

b. Construction of Earth Barricades

After backfill of the instrumentation trench and before construction of the earth barricades, a 1000-foot-square borrow area was laid out about the center of the Phase I donor. This area was first stripped of all debris and vegetation. AFWL personnel then surveyed and staked the location of the Phases I and II earth barricades.

The earth barricades were constructed of local earth, free of any large rocks or other unsatisfactory materials. The soil was a brownish gray, fine-grained, relatively plastic, sandy silt. All the material used to construct the barricades was taken from the 1000-foot-square borrow area by more-or-less uniformly stripping the area down to a maximum depth of 1 foot. The soil was placed in successive horizontal layers not more than 8 inches in depth. Each layer was moistened to obtain optimum moisture content and compacted to 90 percent of maximum Standard Proctor density by a tractor-pulled rubber-tired roller.

c. Construction of Concrete Storage Pads

The reinforced concrete storage pads for Phase I were 30 feet wide by 40 feet long by 9 inches thick with one-half-inch diameter reinforcing bars spaced at 18 inches center to center in both directions, placed 3 inches below the surface of the slab. The tops of all the storage and donor pads were set at the same elevation. The distance from the toe of the earth barricades to the edge of the concrete pads of the donor and acceptors A1, A3, and A4 was 11 feet 6 inches. Acceptor A2 was placed at the toe of the earth barricade on the 30-foot edge of the pad and 11 feet 6 inches from the barricade toe on the 40-foot edge as shown in figure 17.

For Phase II, the additional reinforced-concrete storage pads for acceptors A2 and A3 were 30 feet wide by 20 feet long by 9 inches thick. The reinforcing steel was the same as for the Phase I storage pads. Again, as in Phase I, the tops of all storage pads were at the same elevation. In order to use a K factor of 0.8 (50 feet) between the Phase II donor and acceptor A2, it was necessary to add 10 feet of length to the existing Phase II donor pad which was used for the Phase I acceptor A4. The edge of the donor pad was then 18 inches from the toe of the earth barricade. This made the total distance from the edge of the donor bomb stack to the edge of the acceptor A2

bomb stack exactly 50 feet. Acceptors A1 and A3 were 11 feet 6 inches from the toe of the earth barricade on all barricaded sides.

All of the reinforced-concrete storage pads for Phases I and II were constructed using Type IIIA portland cement designed for a compressive strength of 3000 pounds per square inch at 7 days.

5. RESULTS

a. Acceptor Response

The first and most important result was that no sympathetic simultaneous or delayed detonation of any acceptor was caused by the detonation of a 250,000-pound donor. A postshot photograph is shown in figure 25. Bombs located at K = 1.1 or less from the donors were not accessible until extensive recovery operations were completed. Bombs at K = 2.5 were readily accessible. A discussion of the response of the individual acceptors follows.

(1) Phase I

Acceptor A1 was located 70 feet (K = 1.1) from the donor and rested on a concrete storage pad. The ground swell resulting from the detonation lifted the near side of the acceptor pad and dumped the bombs against the outside barricade. The dunnage was partially burned and the haphazard pile of bombs was completely covered by soil. No bombs were damaged in this acceptor.

Acceptor A2, located 58 feet 6 inches (K = 0.9) from the donor, also rested on a concrete storage pad. The dunnage was partially burned, and the stack was shaken down but not badly disarranged. The stack was covered with earth, and a few bombs, pushed over and away from the stack, were partially or completely exposed. As in acceptor A1, the bombs in this acceptor were not damaged.

In the case of acceptor A3, also resting on a concrete storage pad at a distance of 70 feet, more damage was observed. The dunnage was partially burned and the stack was knocked apart. In addition, the storage pad was damaged and one bomb was destroyed in a low-order detonation. At the time of detonation, the energy released into the soil lifted the near half of the concrete pad, dumping the bombs, and then folded the two halves of the storage pad together. One 750-pound bomb was caught between the two pieces of the slab and detonated low order. The remaining tritonal from this bomb burned and was spread across the storage pad but did not cause any of the other bombs to detonate. The entire disassembled stack was buried.

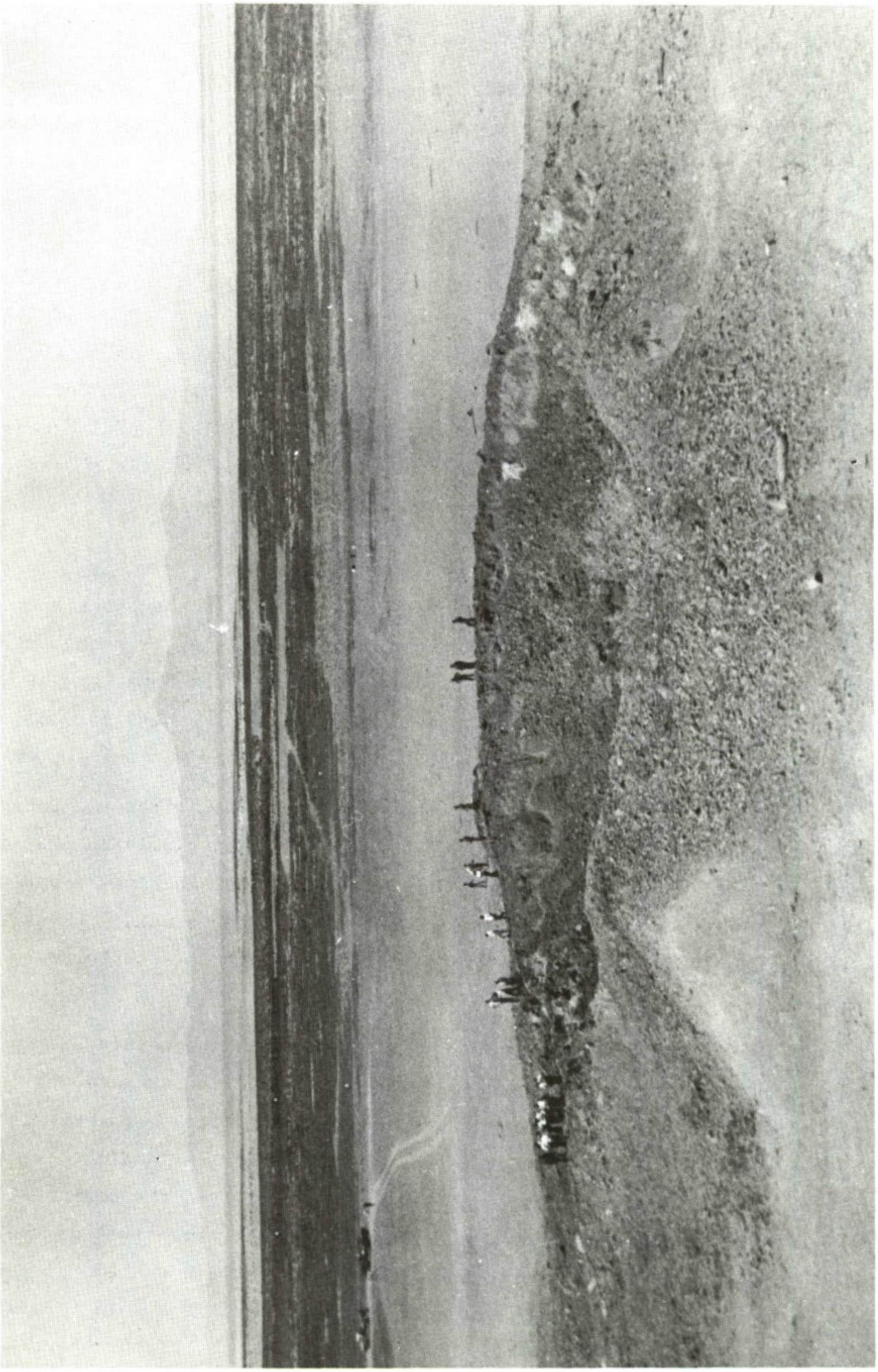


Figure 25. Aerial View of Phase II Crater

Acceptor A4, which was located 158 feet 6 inches (K = 2.5) from the donor, stood on a concrete storage pad. During the test, the dunnage was partially burned, and the upper layer of bombs was disarranged. No bombs were damaged, and the stack was partially covered with soil. However, the bombs were immediately available. The difference between the condition of this stack and that of acceptor A5 stored on the ground should be noted.

Acceptor A5 was located 158 feet 6 inches from acceptor A1 (K = 2.5) and 174 feet from the donor (K = 2.8) and rested on the natural ground surface. Only timber dunnage was placed under the stack to keep the bombs off the ground and properly aligned. The dunnage was partially burned and the stack was completely disarranged by the ground shock. One 750-pound bomb had detonated low order. The nose section and lower half of the bomb body was found on the ground directly under one 2000-pound bomb and positioned between two other 2000-pound bombs arranged in a pyramid. Tritonal from the 750-pound bomb was plastered on nearby 2000-pound bombs and scattered out on the ground over a circular area about 25 feet in diameter. Apparently ground shock caused these bombs to fall from the stack. The 750-pound bomb probably fell from its position on the top layer with the larger bombs then falling on top of it. This 750-pound bomb was the only one damaged in this acceptor.

(2) Phase II

Acceptor A1 was located 70 feet (K = 1.1) from the donor and rested on timber dunnage placed directly on the ground surface. The dunnage was burned, and the stack was shaken down by the detonation, but no bombs were damaged. The entire stack was covered with soil.

Acceptor A2 rested on a concrete pad 50 feet (K = 0.8) from the donor. As in the case of acceptor A1, the dunnage was partially burned, and the stack was disarranged, but no bombs were damaged. The stack was partially rolled away from the donor and completely buried with soil.

The A3 acceptor was at a distance of 70 feet (K = 1.1) from the donor and rested on a concrete storage pad. Other than the partially burned dunnage and stack disarrangement, no damage was incurred. The entire stack was covered with soil. An aerial view of the Phase II crater is shown in figure 25.

The 10 inert M117 bomb bodies located in acceptor A3, as described in paragraph 3, Section III, and shown in figure 19, were mostly tossed outward from the donor. Some were covered with earth but several were thrown clear. Fins were torn off and severely twisted. However, none of the ampoules in the long-delay tail fuzes was damaged. Fuzes were in their normal unarmed condition.

b. Instrumentation

Fifty-seven electronic transducers were installed in Phase I. These included 35 air-pressure transducers, 16 accelerometers and six velocity transducers. Of these transducers, 50 functioned including 30 air-pressure, 14 accelerometers and six velocity transducers. Several of the transducers were lost a few milliseconds after the detonation as expected. However, the initial peak impulse had already been measured and transmitted to the recorder before the transducer was destroyed.

A total of 29 electronic transducers were installed in Phase II. Included in this measurement group were 23 air-pressure transducers and six accelerometers. Twenty-three transducers functioned including 17 air-pressure transducers and six accelerometers. Five of the air-pressure transducers did not function because of a power failure at the recording van before the arrival of the pressure pulse at the transducer location.

In both Phase I and Phase II, the Naval Weapons Center installed a pair of the electromechanical air-pressure gages adjacent to seven stations of AFWL electronic transducers along the extended measurement line normal to the axis of the bombs (figures 23 and 24). In addition, that agency installed pairs of similar transducers at corresponding distances from the donor along a line parallel to the longitudinal axis of the bombs.

(1) Air-Pressure Results

Curves shown in figure 26 indicate the air-pressure data obtained by the two agencies on the individual tests. In figure 27, all the data are combined to develop a single curve, which is plotted on the same graph with a BRL curve which was increased by a factor of 1.23 to convert the TNT energy output to that of tritonal used in these tests. This seems to be excessive

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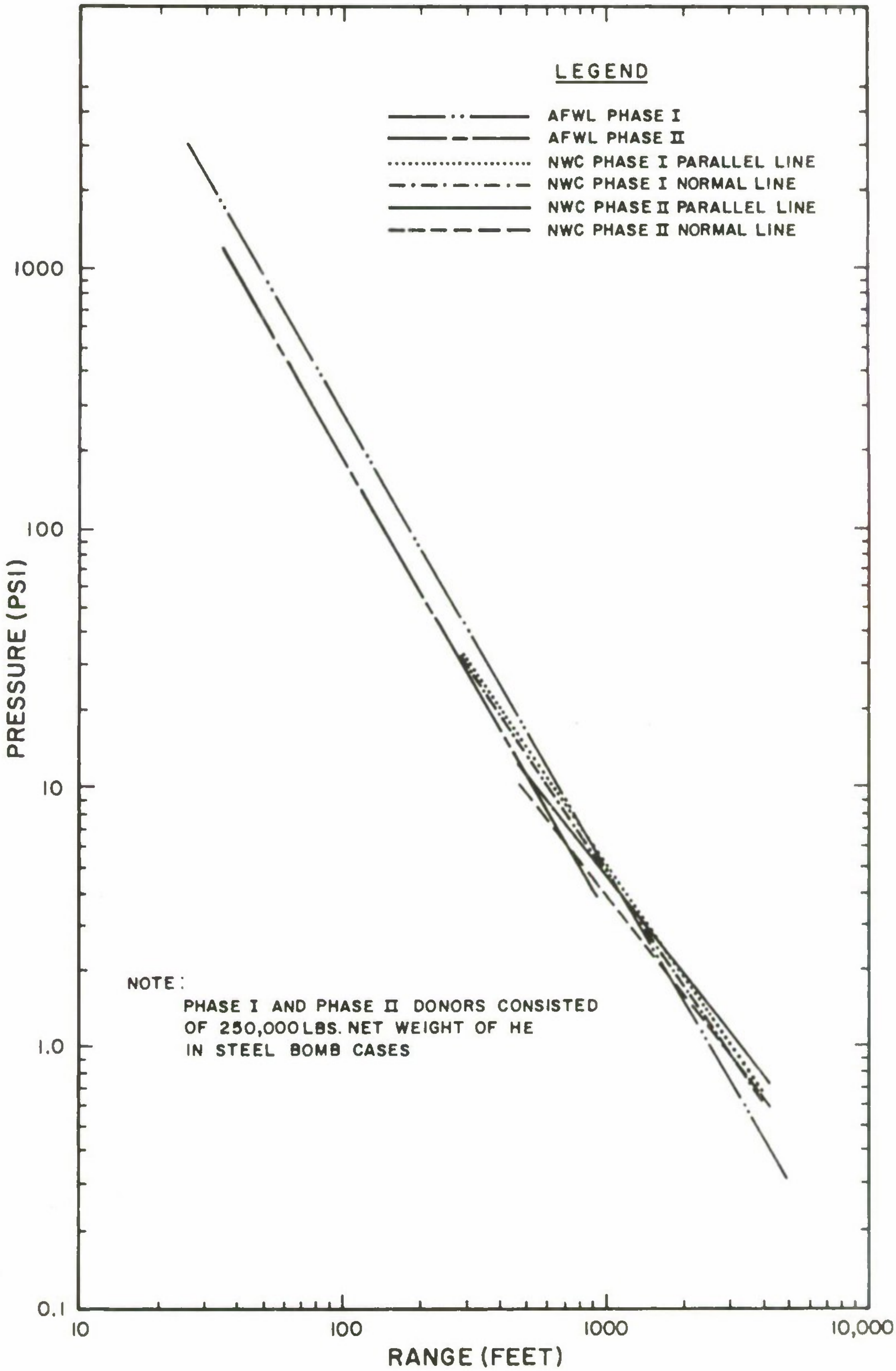


Figure 26. Data Obtained by AFWL and NWS on Phases I and II

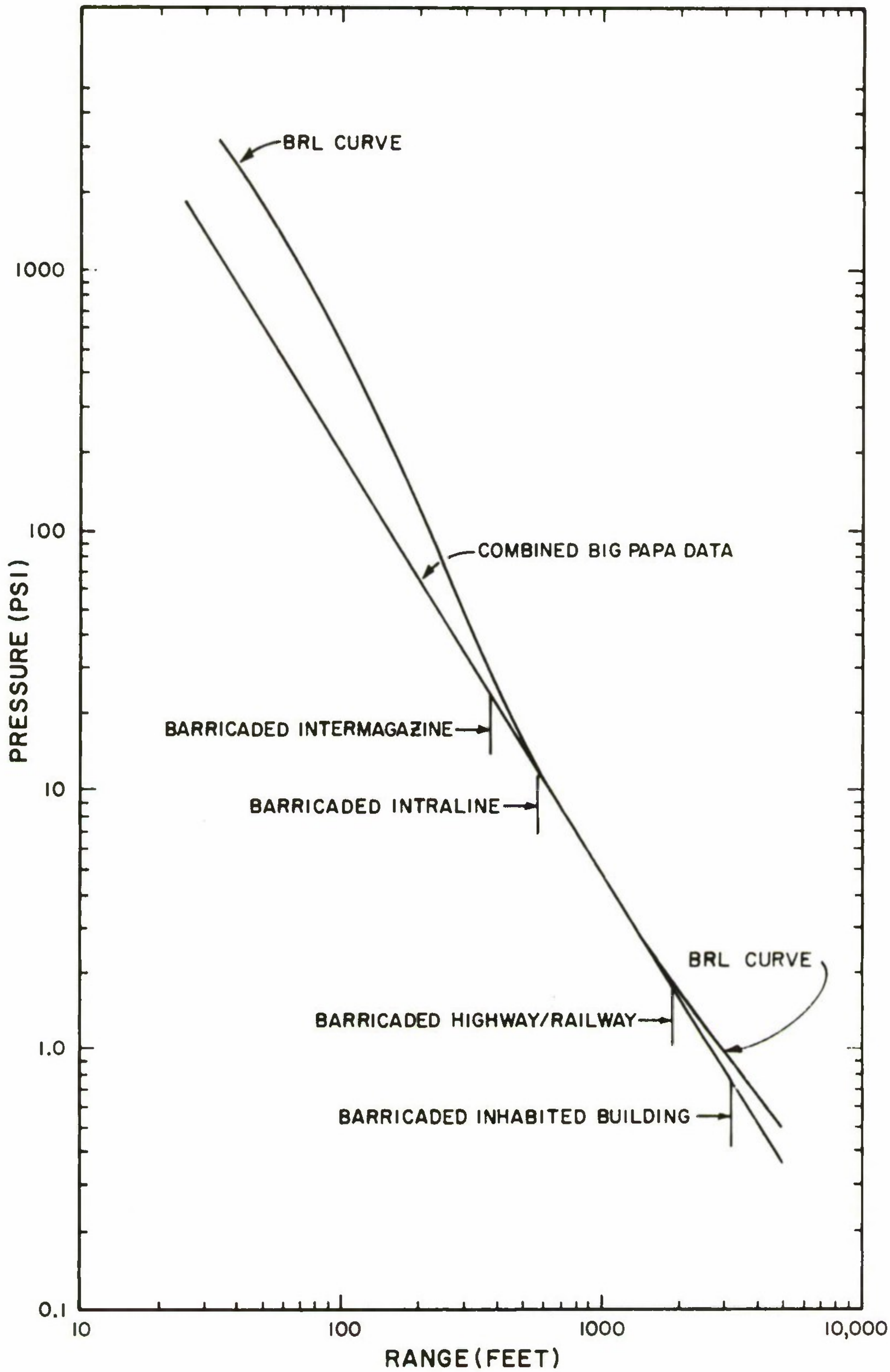


Figure 27. Combined Air-Pressure Data

(2) Acceleration and Velocity Results

Acceleration measurements were made for three purposes: (1) to obtain a measure of the attenuation of vertical acceleration with distance; (2) to obtain a comparison of the input accelerations into a stack of bombs on a concrete pad versus that on natural ground; and (3) to determine the motion of the barricade.

The attenuation of vertical acceleration with distance is shown in figure 28. Three data points were used in the development of this curve. One additional measurement, taken at 334 feet from the Phase II detonation center, was omitted because it indicated approximately three times the expected amplitude at that distance. The transducer location was directly behind the crater resulting from the Phase I test, and the result appeared to have been altered by the existence of that crater. Other measurements were located in or immediately behind the barricade, and these data indicated probable influence therefrom.

The peak vertical acceleration recorded for the accelerometer placed 6 inches below the top surface of the 9-inch thick concrete pad under acceptor A1 of Phase I was 110 g, whereas the peak vertical acceleration recorded for the accelerometer placed 6 inches below the ground surface under acceptor A1 of Phase II was 290 g. It would be reasonable to expect less acceleration in acceptor A1 of Phase I because its mass (including the concrete slab) was approximately four times that of acceptor A1 of Phase II. The horizontal acceleration was found to be of the same order of magnitude (approximately 40 g) in both types of stack foundations.

Initial motion of the barricade was found to be outward and upward while the earth below the barricade appeared to move down and away from the blast. This was borne out both by the accelerometers and the velocity transducers. The results from both types of transducer are presented in figures 29 and 30. The motion of the barricade at its centroid was found to lag behind the passage of the pressure front by about 5 to 20 milliseconds. In fact, the pressure front had passed the entire barricade structure (a total duration of 8 msec) before centroidal motion began.

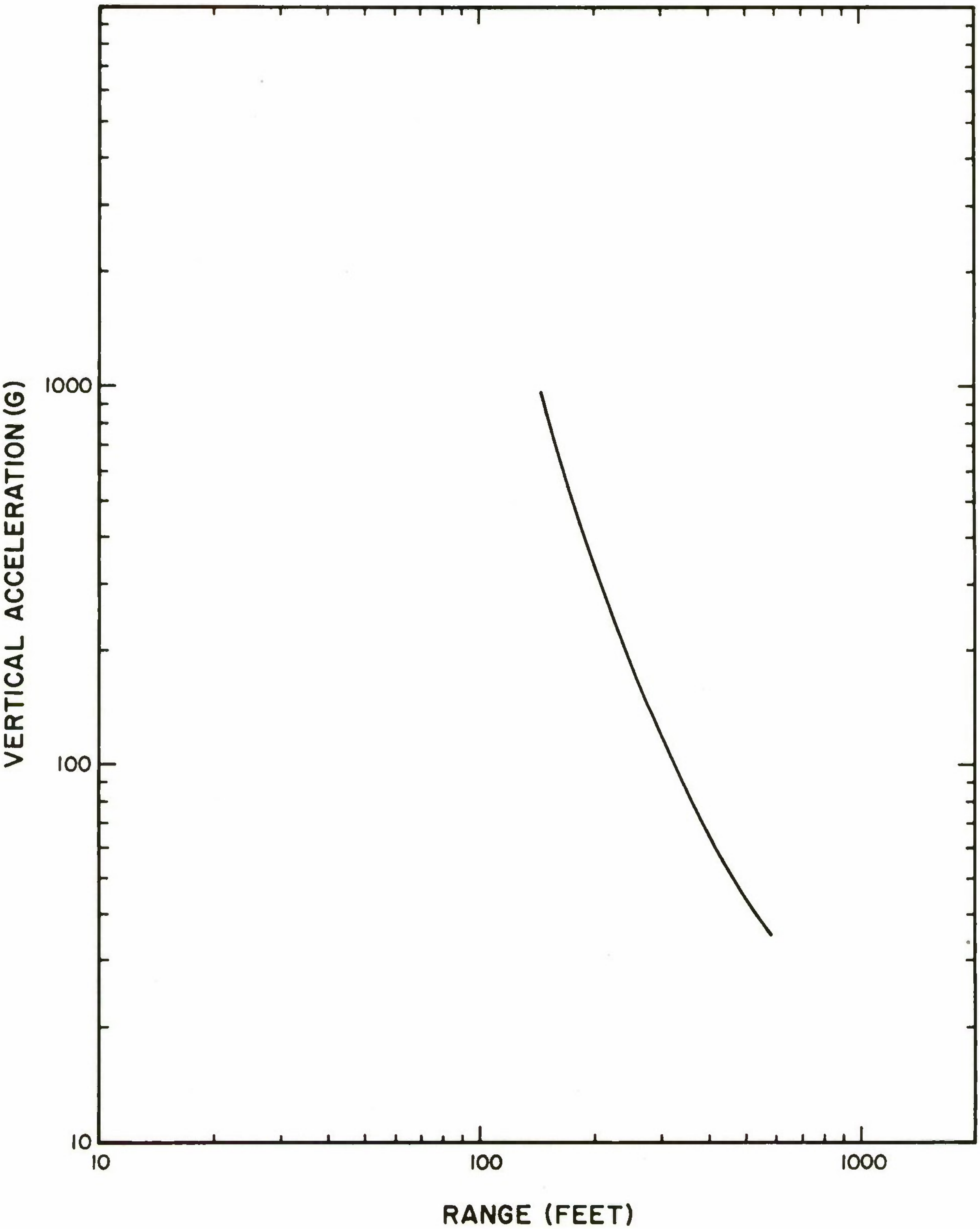


Figure 28. Attenuation of Vertical Acceleration versus Distance

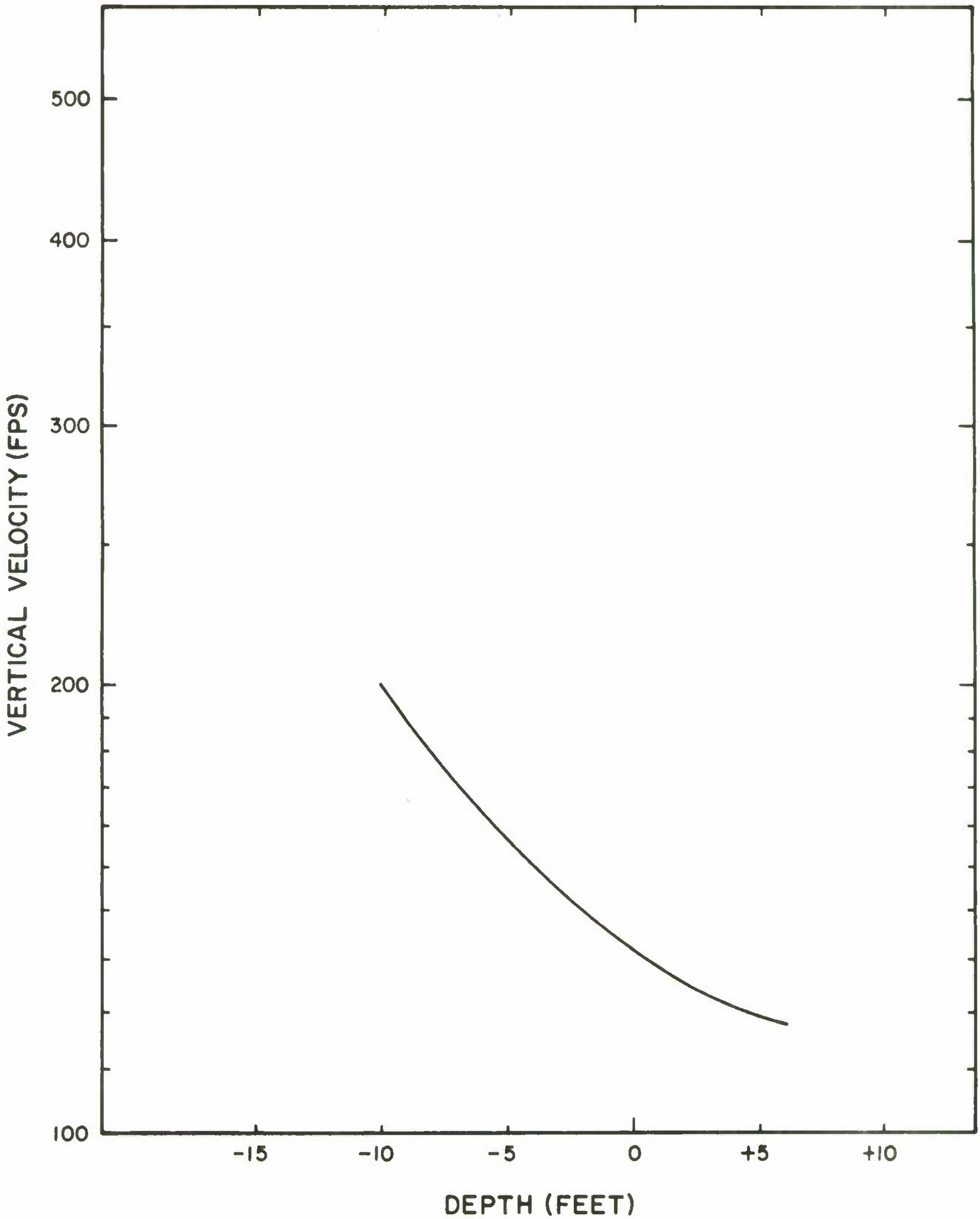


Figure 29. Vertical Velocity versus Depth

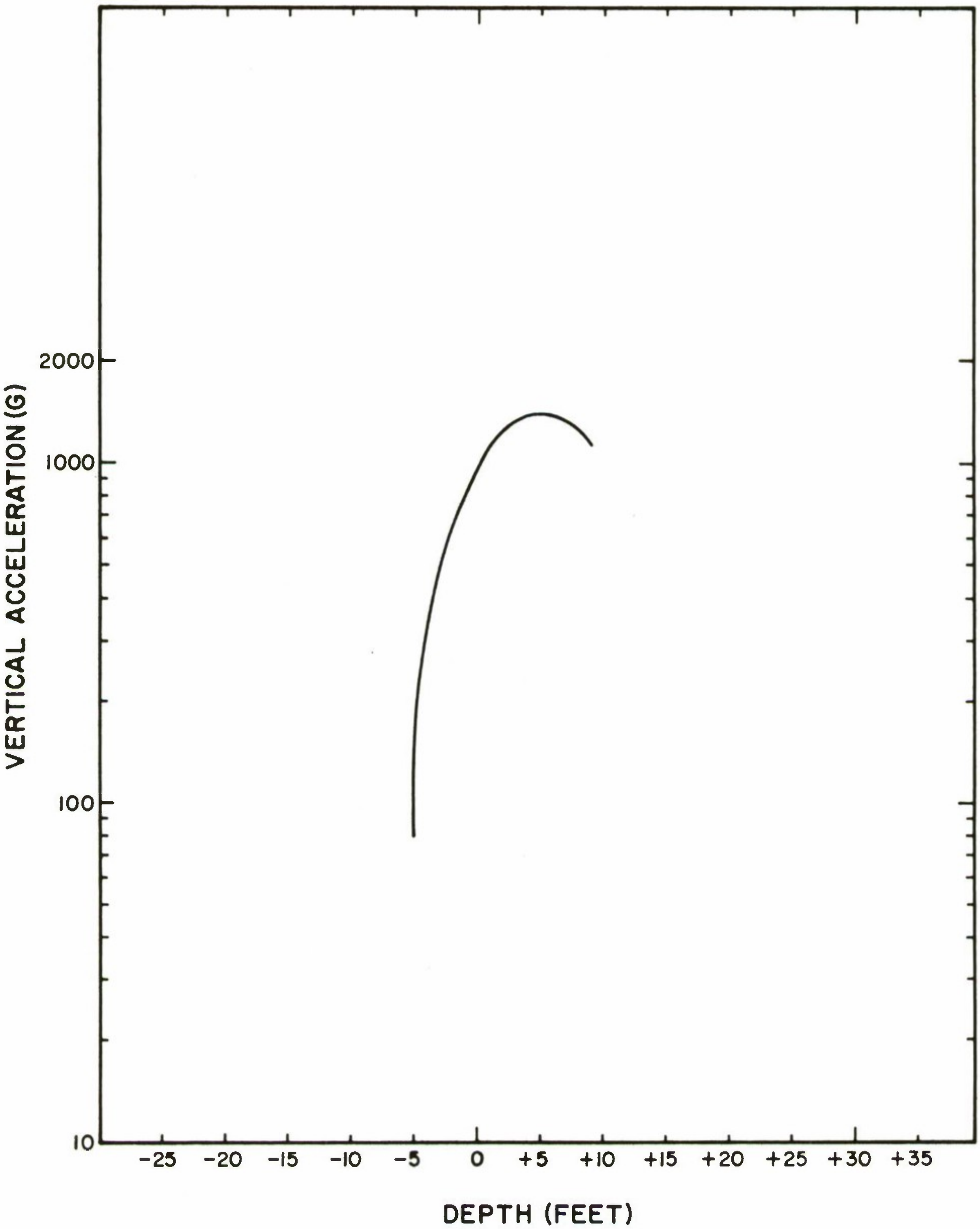


Figure 30. Vertical Acceleration versus Depth

c. Fragmentation Survey

After the Phase I detonation, the primary fragments (pieces of bomb casing) found on the 10 fragmentation survey areas were collected, weighed, and counted. The location of each individual fragmentation area in relation to the donor is shown in figure 2. The results of the Phase I fragment survey are given in table VI.

Phase II fragmentation survey was conducted in the same manner as Phase I. The location of the fragmentation areas for Phase II is illustrated in figure 5. Table VII gives the results of this fragment survey.

d. Crater Data

The craters resulting from the Phase I, II and III detonations were surveyed. Cross sections for the Phase I and II craters were taken every 45° from an assumed north.

(1) Phase I

The diameter of the apparent crater for Phase I measured at the top of the outermost rim ranged from 170 to 184 feet. The depth of this crater ranged from 17.5 to 20.5 feet below the original grade (top of the concrete donor pad). The height at the outermost rim ranged from 5.0 to 16.0 feet above the top of the destroyed donor pad. Figures 31 and 32 show a plan and four cross sections of the Phase I crater.

(2) Phase II

The diameter of the Phase II apparent crater measured at the top of the outermost rim ranged from 168 to 180 feet. The depth of this crater ranged from 22.0 to 23.0 feet below the top of the destroyed donor pad. The height at the outermost rim ranged from 5.0 to 12.0 feet above this reference elevation. A plan and four cross sections of the Phase II crater are shown in figures 33 and 34.

e. Photography

In Phase I, five 3000-frame-per-second cameras were used (see table II). The only image visible on this film is the fireball and a rising mushroom-shaped cloud.

After viewing the Phase I film, it was decided to increase the frame rate for the high-speed cameras to be used in Phase II to 5000 frames per second (table III). The high-speed film for both Phases I and II clearly shows the blast wave moving over the earth barricades.

Table VI

RESULTS OF PHASE I FRAGMENTATION SURVEY

Weight interval (pounds)	Number of fragments recovered									
	1W	1S	2W	2S	3W	3S	4W	4S	5W	5S
0-1/4	2980	2210	1544	2015	27	24	---	1	---	---
1/4-1/2	121	117	87	133	36	28	---	---	---	1
1/2-3/4	39	34	32	28	24	11	---	1	---	---
3/4-1.0	22	16	19	16	9	2	---	---	---	---
1.0-1 1/4	18	9	4	8	3	2	---	---	---	---
1 1/4-1 1/2	13	2	4	---	3	---	---	---	---	---
1 1/2-1 3/4	5	4	2	3	4	---	---	---	---	---
1 3/4-2.0	2	6	2	2	1	---	---	---	---	---
2-2 1/4	4	---	1	2	---	1	---	---	---	---
2 1/4-2 1/2	1	---	1	1	---	---	---	---	---	---
2 1/2-2 3/4	4	---	---	---	---	1	---	---	1	---
2 3/4-3.0	5	1	1	---	1	---	---	---	---	---
3.0-3 1/4	2	---	---	---	---	---	---	---	---	---
3 1/4-3 1/2	2	---	---	---	1	---	---	1	---	---
3 3/4-4.0	1	---	---	---	---	---	---	---	---	---
4 1/4-4 1/2	1	1	---	---	---	---	---	---	---	---
4 1/2-4 3/4	---	---	---	1	---	---	---	---	---	---
10-10 1/4	1	---	---	---	---	---	---	---	---	---

Table VII

RESULTS OF PHASE II FRAGMENTATION SURVEY

Weight interval (pounds)	Number of fragments recovered									
	1W	1S	2W	2S	3W	3S	4W	4S	5W	5S
0-1/4	516	1011	5718	637	88	21	2	1	---	1
1/4-1/2	114	155	372	80	70	14	7	---	---	1
1/2-3/4	37	70	133	19	32	5	7	1	---	---
3/4-1.0	18	28	39	6	14	2	5	---	---	---
1.0-1 1/4	15	11	33	7	11	1	5	---	---	---
1 1/4-1 1/2	7	7	23	3	3	1	---	---	---	3
1 1/2-1 3/4	4	8	7	2	---	---	4	---	---	---
1 3/4-2.0	3	6	7	---	1	---	1	---	---	---
2.0-2 1/4	6	2	7	5	3	---	1	---	---	---
2 1/4-2 1/2	---	1	4	---	---	---	1	---	---	---
2 1/2-2 3/4	1	---	1	1	1	1	1	---	---	---
2 3/4-3.0	4	1	4	---	---	---	---	---	---	---
3.0-3 1/4	---	---	---	---	---	---	---	---	---	---
3 1/4-3 1/2	3	---	---	2	1	---	---	---	---	---
3 1/2-3 3/4	1	---	2	---	---	1	---	---	---	---
4.0-4 1/4	---	---	---	2	---	1	---	---	---	---
4 1/4-4 1/2	1	---	1	---	1	---	---	---	---	---
8.0-8 1/4	---	2	---	---	---	---	---	---	---	---
8 3/4-9.0	---	1	---	---	---	---	---	---	---	---

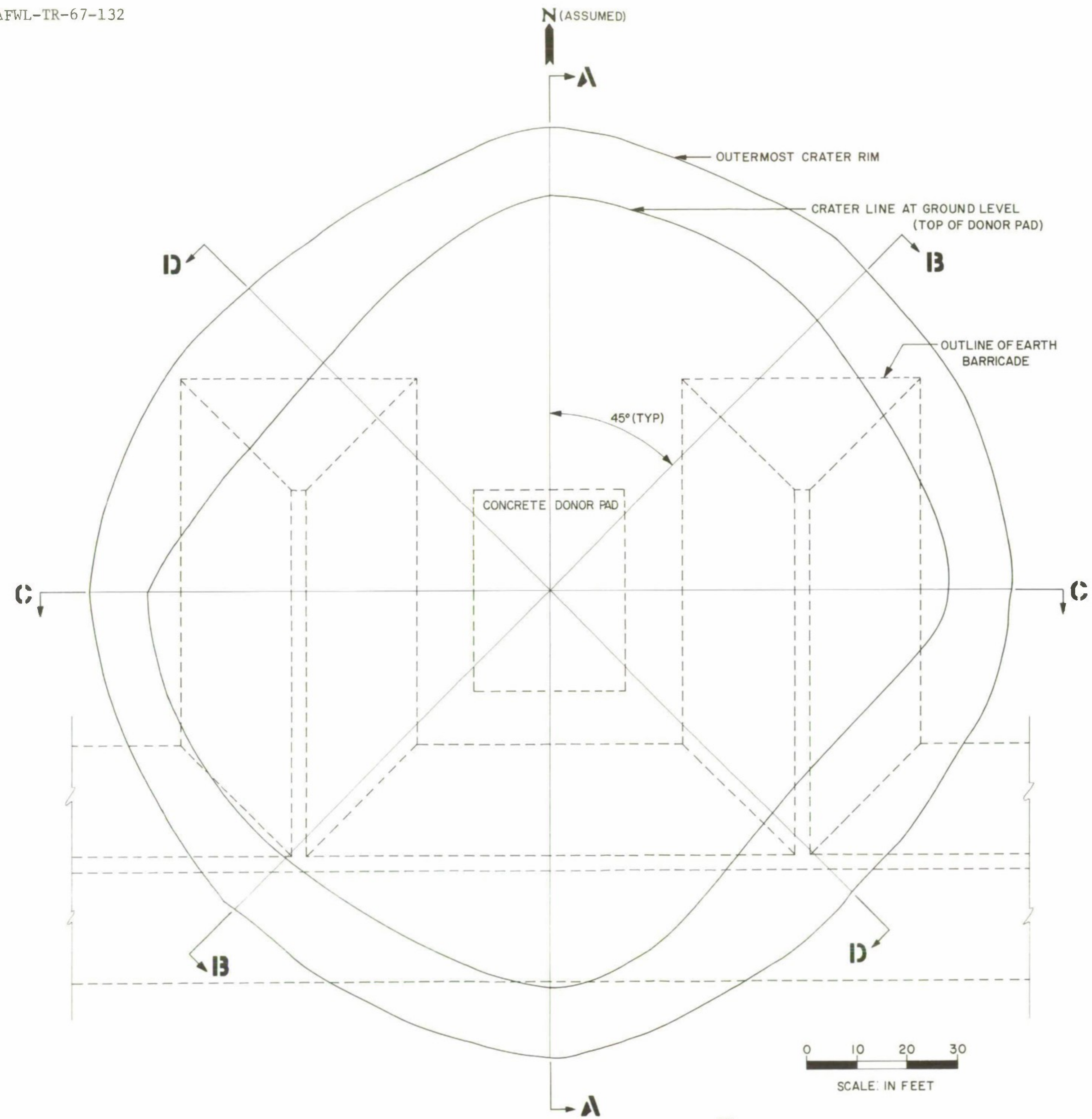


Figure 31. Plan View of Phase I Crater

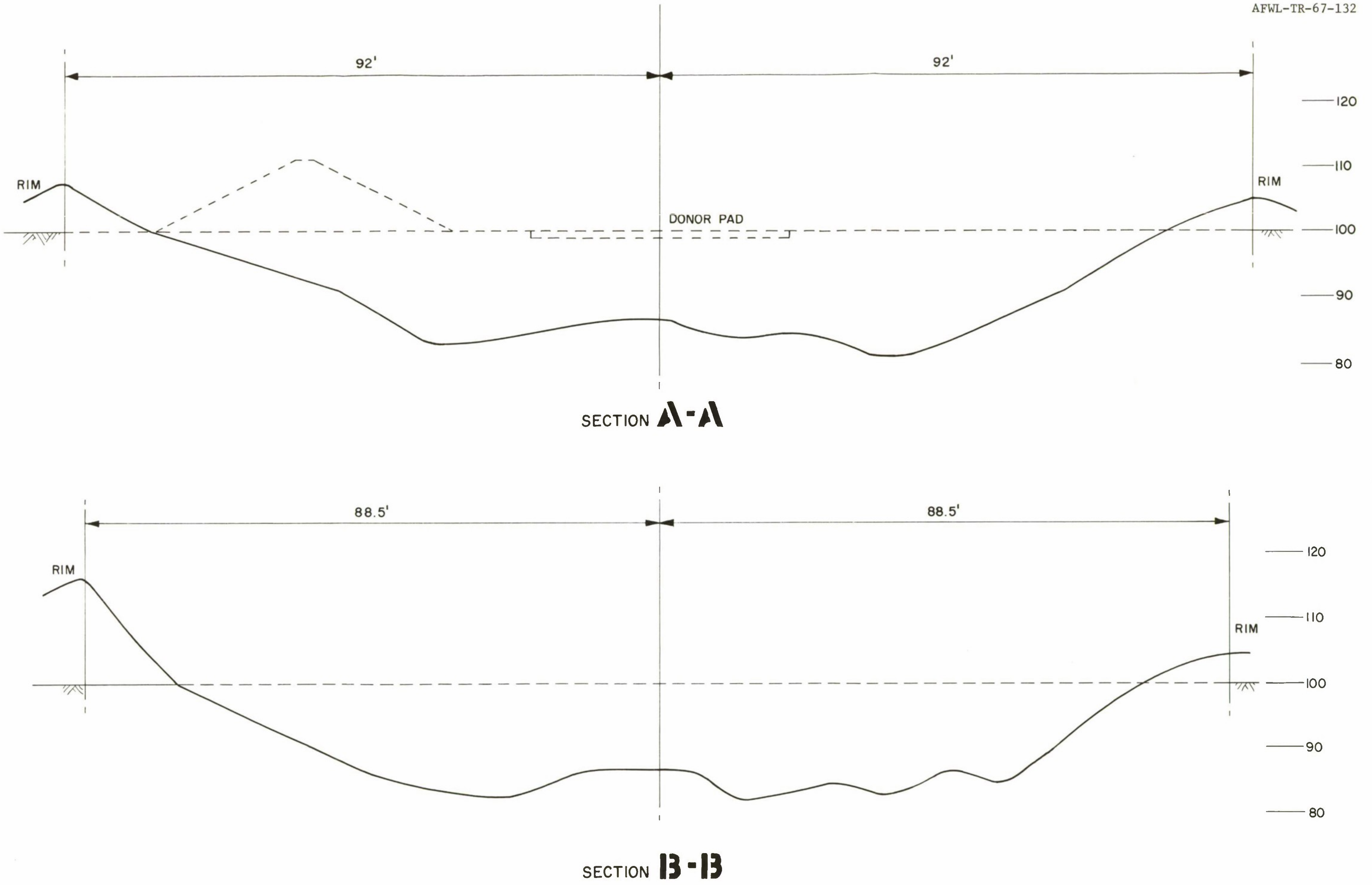
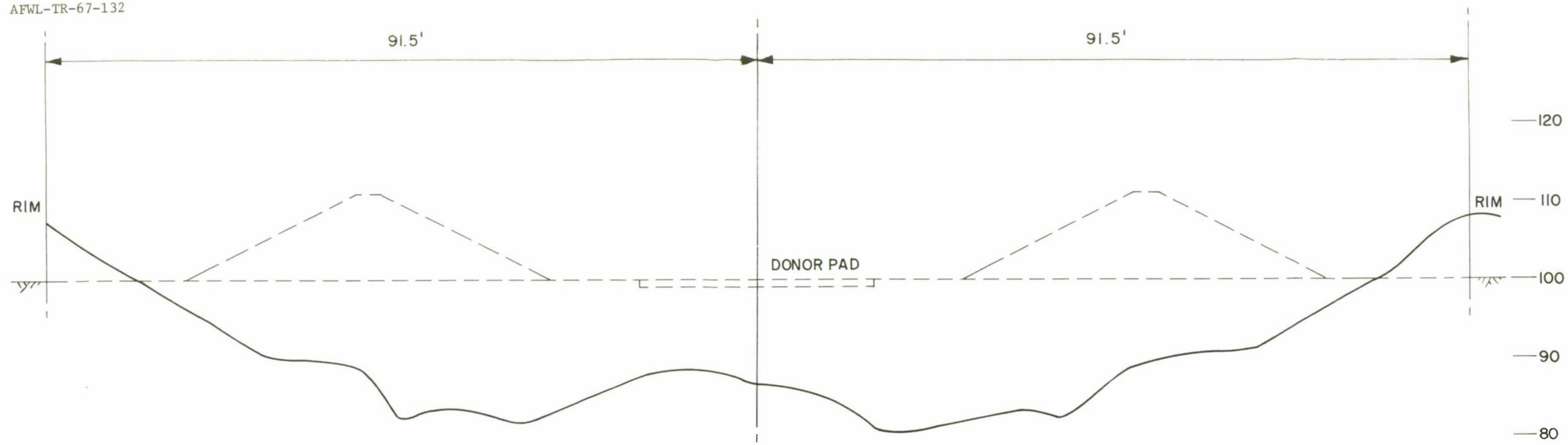
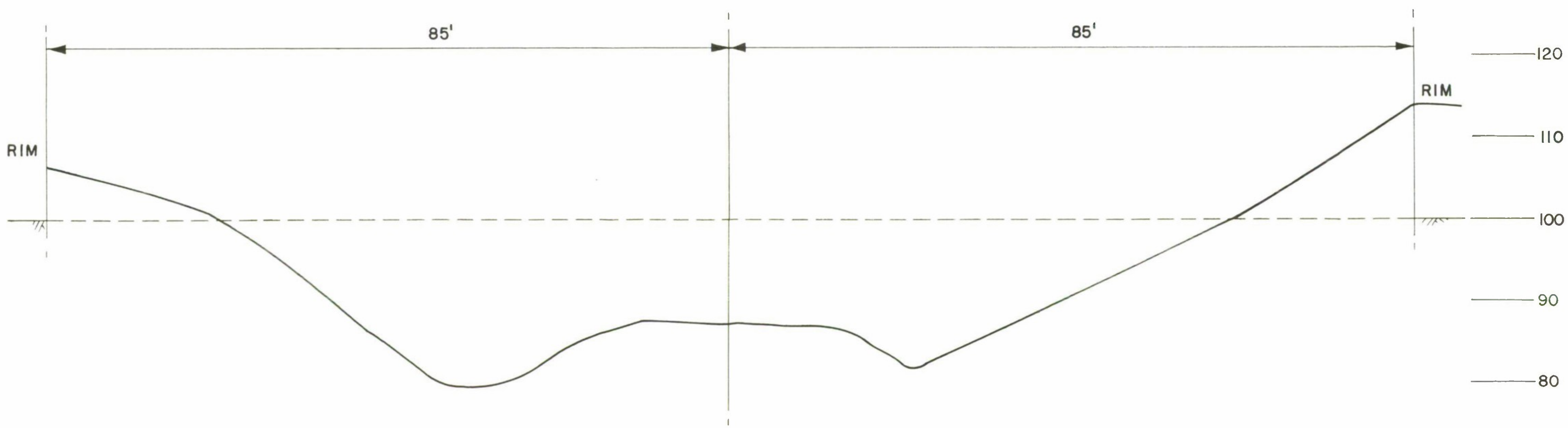


Figure 32. Cross Sections of Phase I Crater



SECTION C-C



SECTION D-D

Figure 32 (cont'd). Cross Sections of Phase I Crater

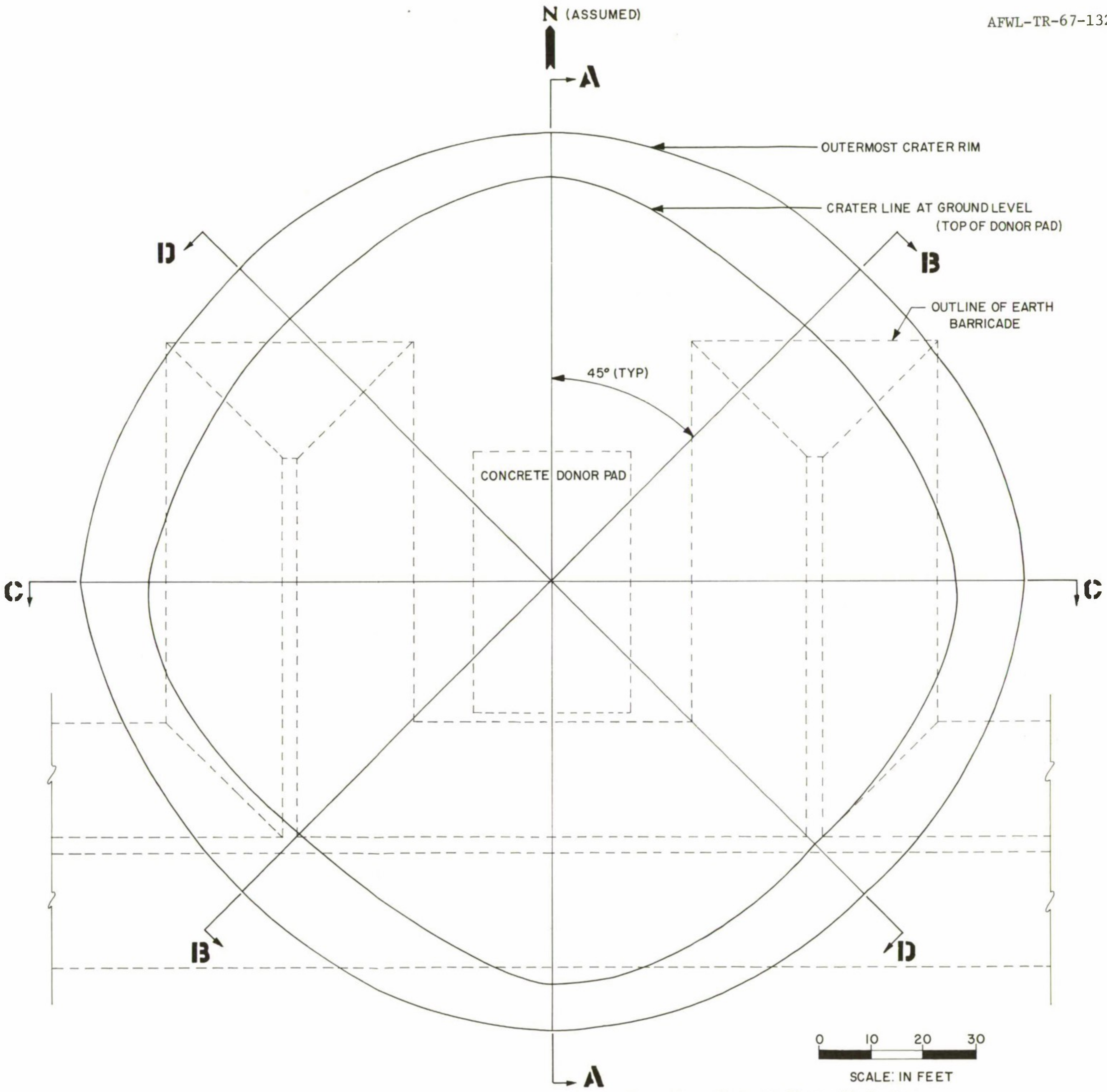


Figure 33. Plan View of Phase II Crater

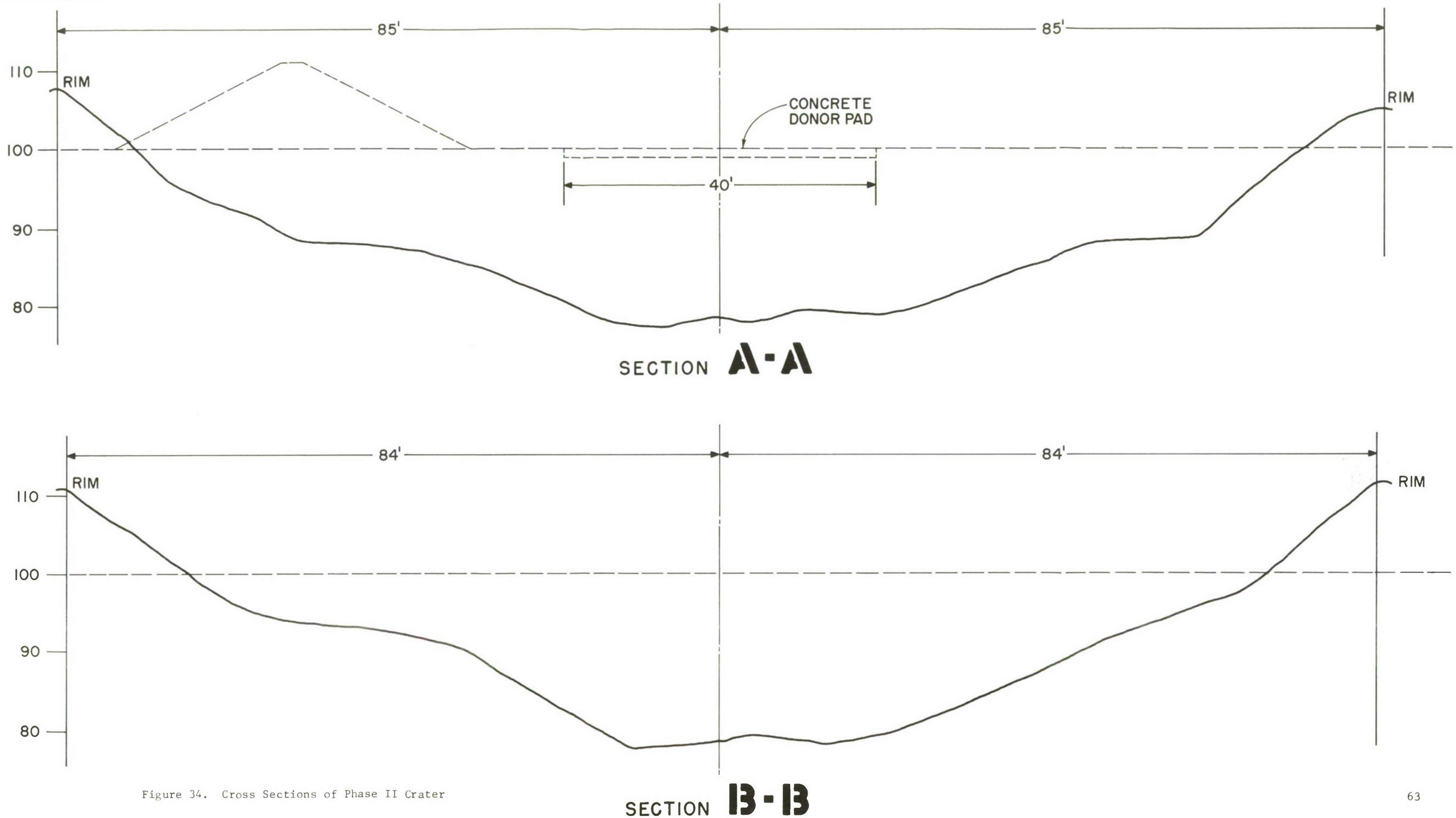
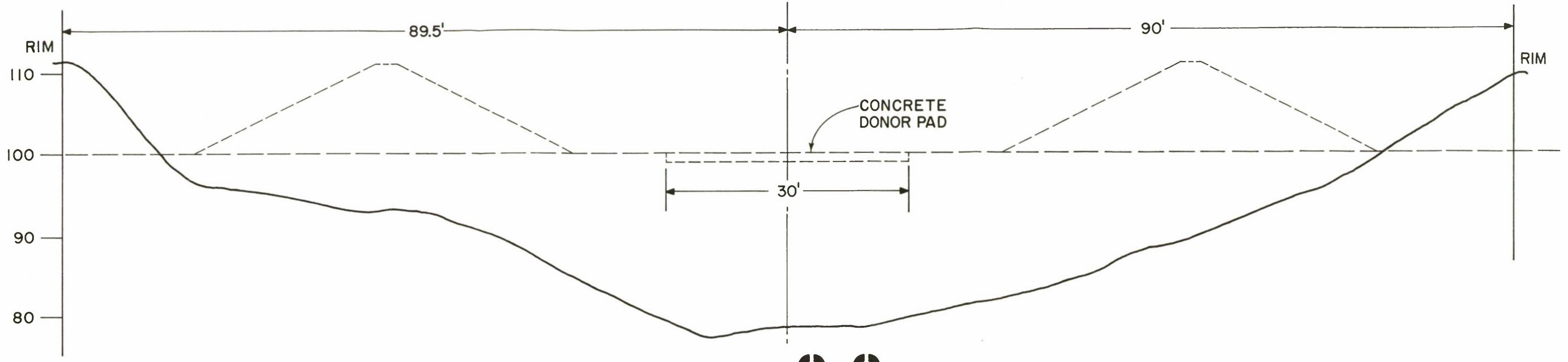
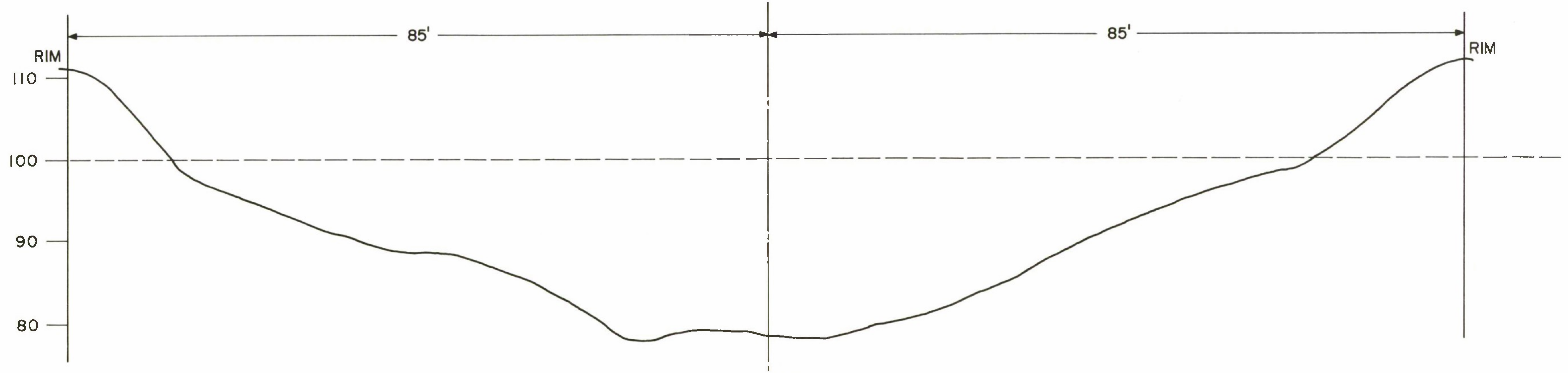


Figure 34. Cross Sections of Phase II Crater



SECTION C-C



SECTION D-D

Figure 34 (cont'd). Cross Sections of Phase II Crater

SECTION IV

PHASE III

1. GENERAL

Phase III of the BIG PAPA test series was the last performed. This test was fired at 1030 hours (MDT) on 12 October 1967. Originally, Phase III was scheduled to precede the firing of Phase IV, but because of the complexity of Phase III and the relative simplicity of Phase IV, it was decided to interchange the two tests.

2. DESCRIPTION OF PHASE III

Phase III was a test of optimum barricade geometry and barricade materials. Heavy periodic rains resulting in reduced effectiveness and costly maintenance made it necessary to look for a substitute for the standard earth barricade. At many bases, only sand was available and this was found to be unsuitable for earth barricade construction. Therefore, Phase III was designed to discover a more suitable barricade for use in any location where the use of earth barricades was not feasible.

This test arrangement consisted of one hexagonal reinforced-concrete donor pad with six different types of barricade spaced 25 feet from each edge of the pad. Approximately 103,000 pounds of HE was contained in the donor bomb stack. Directly behind each barricade at 50 feet (K factor of 1.1) from the edge of donor was a foam-concrete simulated acceptor. These six simulated acceptors were constructed on compacted earth fill. The tops of the acceptors were constructed to a height of 7 feet above the top of the donor pad. Two additional foam-concrete acceptors were placed at 80 feet center to center of the acceptors behind Barricades A and D. These latter four foam concrete acceptors extended 2 feet above the top of the donor pad. There were a total of 10 foam-concrete simulated acceptors used in Phase III. A layout and aerial view of Phase III is shown in figures 35 and 36.

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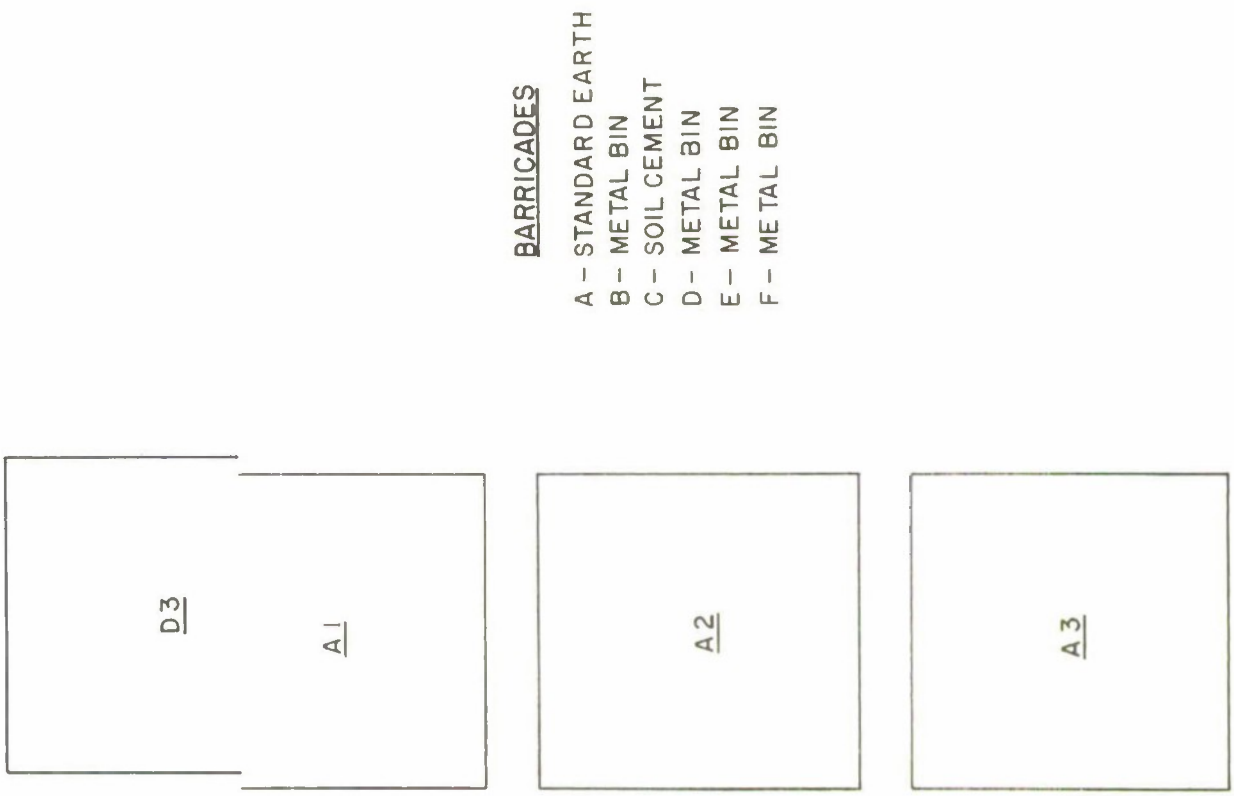
BARRICADES
A - STANDARD EARTH
B - METAL BIN
C - SOIL CEMENT
D - METAL BIN
E - METAL BIN
F - METAL BIN
D3
A1
A2
A3

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Figure 36. Aerial View of Phase III Test Configuration

3. CONSTRUCTION PROCEDURES

a. Instrumentation Placement

After Phases I and II were completed, an additional 1100 feet of 5-foot-deep trench was excavated to the area selected for Phase III. The data-transmission cables were prepared as previously described and were laid to points directly under the six barricades. As the barricades were erected, holes were cut in the faces adjacent to the donor, and the air-pressure transducers were bolted directly to the barricade material. In the case of Barricade C (the soil-cement barricade), the transducers were mounted to the forms and the barricade material was placed around them. Those transducers mounted on Barricade A (the standard earth barricade) were mounted in the same manner as in Phases I and II. All accelerometers were wired to the recording van before the fill material was placed inside the barricades, and were located at the centroid of the main section of the barricade at the time of filling.

Twenty-four electronic transducers were installed in Phase III. These included 12 air-pressure transducers and six horizontal and vertical accelerometers. The air-pressure transducers were located one-quarter the distance from each end of the barricade main section facing the donor, and at one-half the barricade height. In the case of accelerometers, a vertical and a horizontal transducer were placed at the centroid of the barricade as described above.

To protect the air-pressure transducers from fragmentation damage at detonation, a 1-inch thick by 3-inch diameter steel plate was placed over the transducer location. The plate was bolted to the transducer canister and was maintained at a distance of 3 inches from the transducer by appropriately designed legs. This provided transducer survival for sufficient time to record the air pressure.

b. Construction of Barricades

(1) Barricade A

Barricade A was the same as the standard earth barricade which was used in Phases I and II, and it was constructed from the same soil used in those tests. The barricade was 9 feet in height and 30 feet in length with a 3-foot wide berm at the top (figure 37). It was constructed in the same manner previously described in Section III. The erection time for this barricade was 0.50 manhour per linear foot of barricade.

(2) Barricade B

Barricade B was a commercially available metal bin-type barricade* presently in use in SEA combat zones for construction of aircraft revetments. For this test a wall 9 feet 4 inches high was constructed. The width of the barricade was 5 feet 6 inches measured from the outer edge of the columns. Forty linear feet of this barricade were constructed; this consisted of four 10-foot long bin-type sections. Three of these 10-foot sections made up the main section of the barricade with one 10-foot section used as a right-angle leg. A plan and elevation drawing and structural details of Barricade B are shown in figures 38 and 39.

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*Armco metal bin manufactured by Armco Steel Corp., Middletown, Ohio.

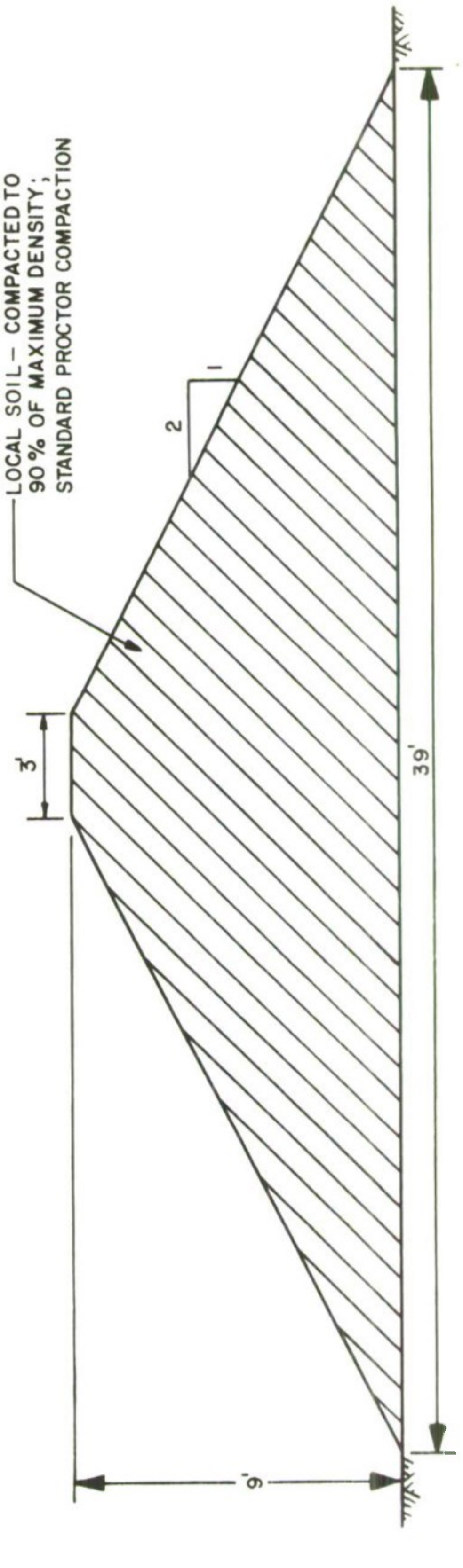


Figure 37. Cross Section of Barricade A

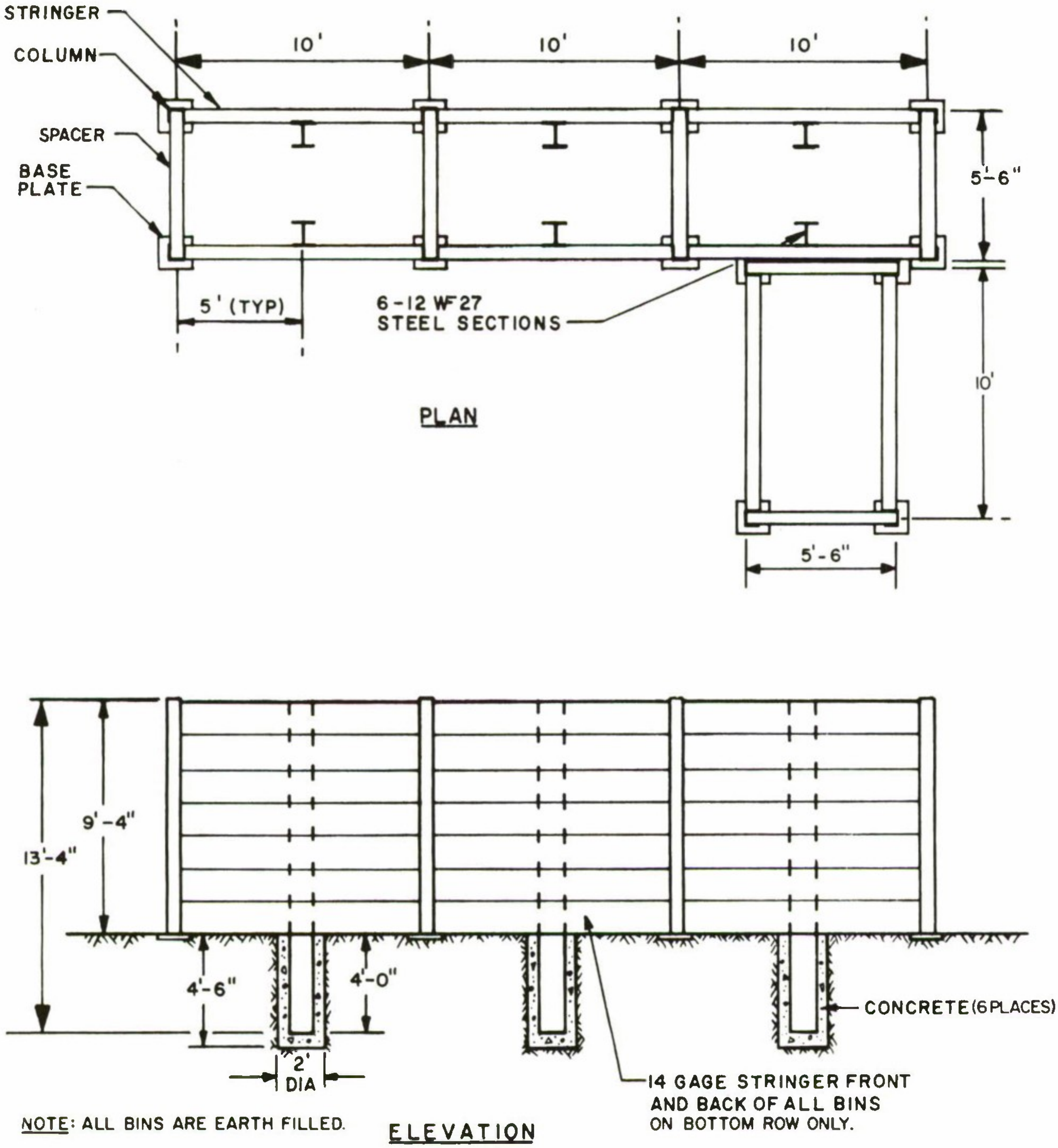


Figure 38. Plan and Elevation of Barricade B

1.	Column	Vertical member connecting all other units
2.	Column Cap	Cover for front column
3.	Stringer stiffener	Top flange protector
4.	Stringer	Horizontal longitudinal members in front and rear walls
5.	Connecting channel	Connector for attaching stringers to columns
6.	Spacer	Transverse members that separate the front and rear columns
7.	Bottom spacer	Special bottom transverse member
8.	Base plate	Installation plate on which the column rests
9.	1¼" x ⅝" bolts	
10.	⅝" nuts	
11.	⅝" spring nuts	

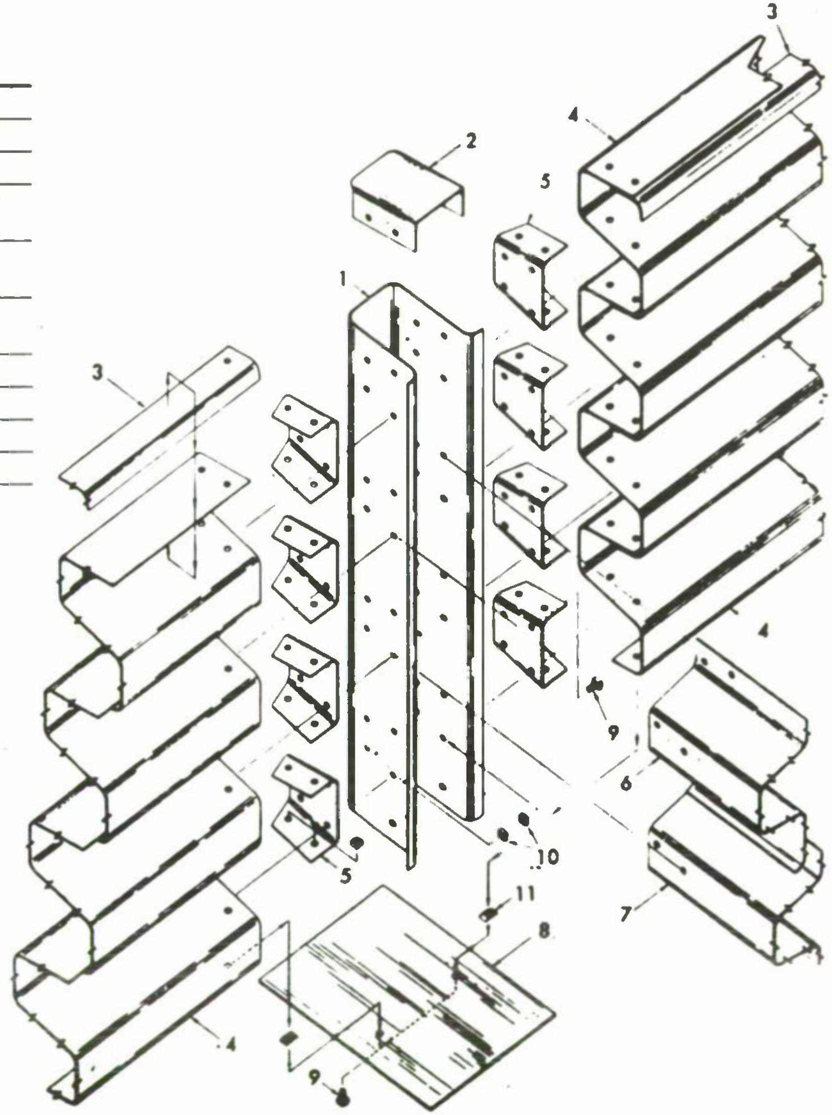


Figure 39. Typical Column Assembly for Barricade B

This barricade was erected with no major difficulty. Six 12WF27 deep steel wide-flange beams, 13 feet 4 inches in length, were embedded in 4 feet of concrete on the inside of the front and back faces of the three 10-foot bin sections. The 2-foot diameter by 4.5-foot deep holes for the footings on all four metal barricades were drilled with a truck-mounted power auger. The wide-flange sections were used to give the metal bins additional bracing and also to duplicate, as much as possible, Barricade D which was designed to have columns embedded in concrete.

The time required to construct this barricade, not considering the installation of the wide-flange sections, was 2.26 manhours per linear foot. Considering the wide-flange sections, the total erection time was 2.41 manhours per linear foot. The equipment needed to erect this barricade included hand wrenches, ratchets and sockets.

All four metal barricades were filled with local soil using a 3-1/2-cubic-yard front-end loader. This operation took approximately 1 hour for each of the four metal bin-type barricades. Photographs of various stages of Barricade B construction are shown in figure 40.

(3) Barricade C

Barricade C was constructed of soil-cement. It was 9 feet high and 37 feet long with 30 feet of this length composing the front face and the remainder forming the right-angle leg. A 3-foot wide berm was maintained at the top of the barricade with the front and back faces sloping 1 on 3 (1 horizontal to 3 vertical, see figure 41).

(4) Barricade D

Barricade D was a steel-frame bin-type structure designed by Air Force Office of Civil Engineering. The height of the barricade was 9 feet, and the clear inside width (from siding to siding) was 5 feet. The length was 37-1/2 feet (see figure 42) consisting of a 30-foot main section and a 7-1/2-foot right-angle leg.

This barricade was fabricated, delivered to the test site, and erected without major difficulty. A total of 13 columns were embedded in 4 feet of concrete throughout the length of the barricade. The erection of this barricade required more skill than the others.

(a)

(b)

Figure 40. Stages of Construction of Barricade B

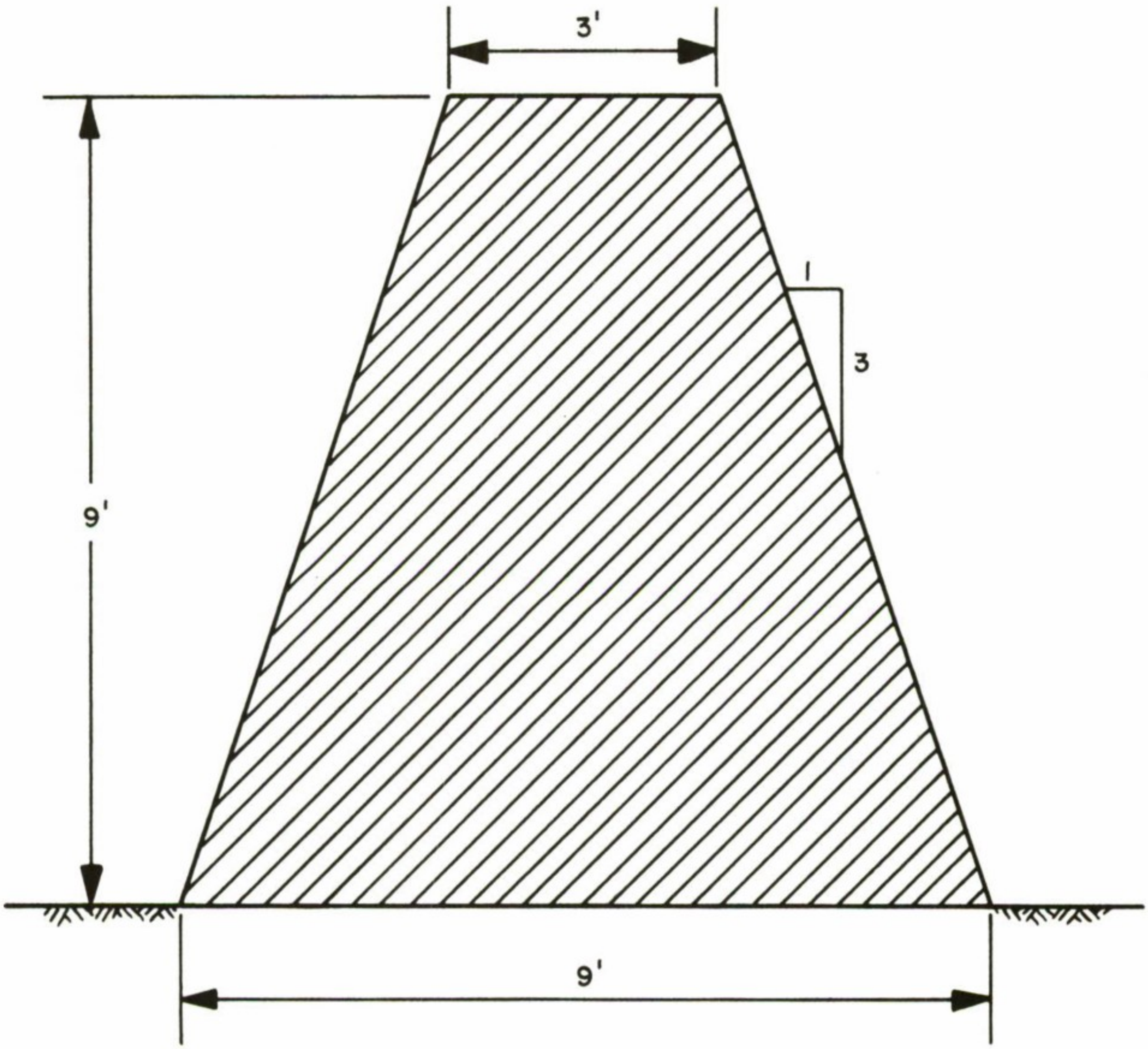
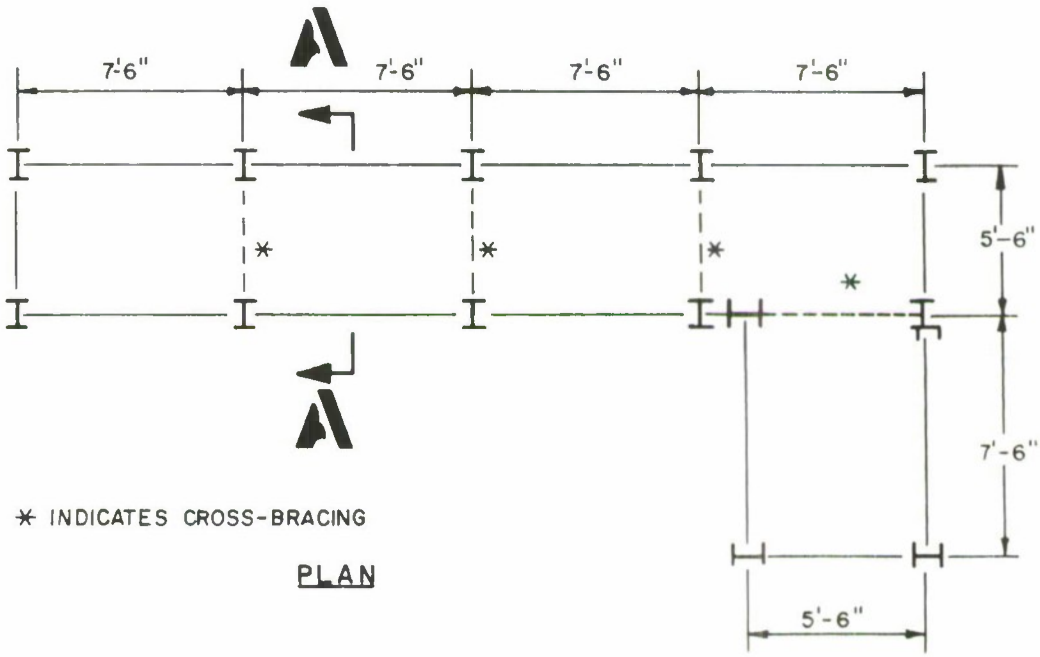


Figure 41. Cross Section of Barricade C



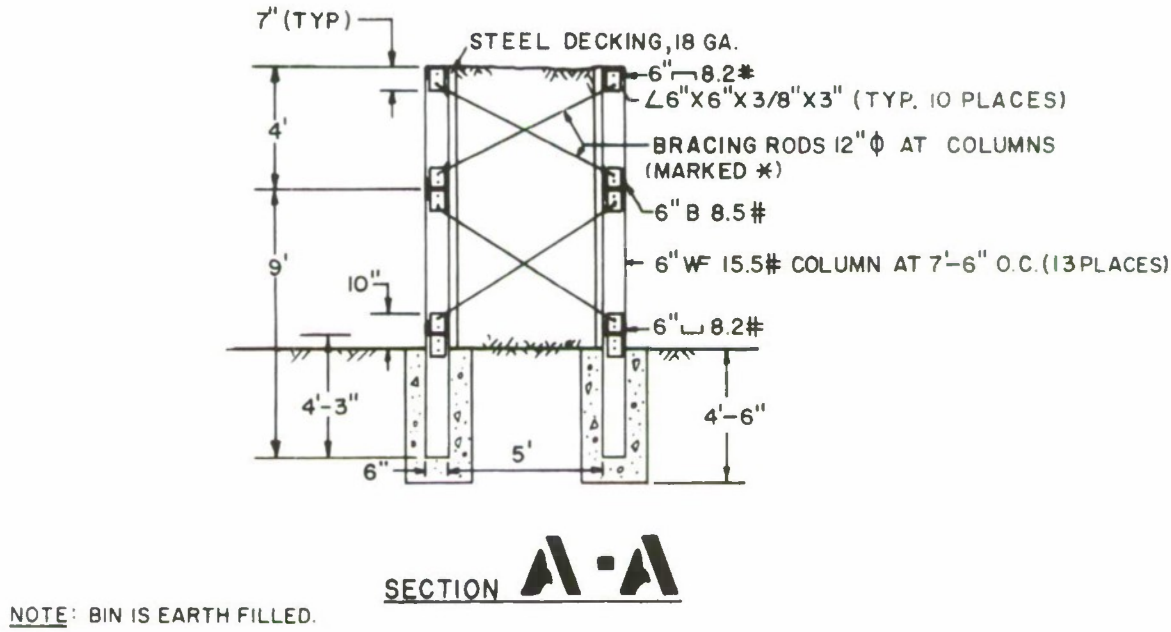


Figure 42. Plan and Elevation of Barricade D

The time required to construct this barricade was 1.43 manhours per linear foot. The equipment required consisted of hand wrenches, ratchets and sockets, and a small front-end loader to lift the columns into position. This barricade was filled in the the same manner as Barricade B. Figure 43 shows the different construction stages for Barricade D.

(5) Barricade E

Barricade E was a commercially available barricade* and consisted of only two items. The main item was a 4-foot long by 2.5-foot wide galvanized-steel panel (18 gage). These panels were connected with special quick-fasteners. The barricade was 5 feet wide, 8 feet high and 40 feet long (a 30-foot main section with a 10-foot leg forming a right angle, see figure 44). The individual panels were joined to form a bin 4 feet high and 2.5 feet on each side with both ends open. Two of these sections were connected side-to-side to form a 5-foot width. Another 4-foot high bin section was fastened on top of the lower section to provide an 8-foot height.

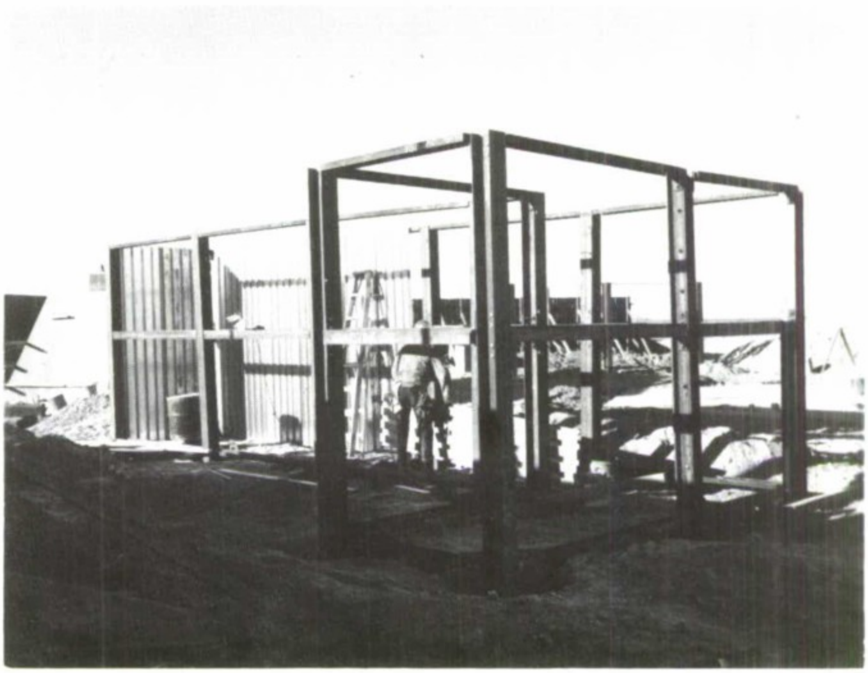
This barricade was braced along the 30-foot main section on the inside of both the front and back faces with eight 12WF27 steel sections. There were four of these steel sections on each face embedded in concrete as previously described.

Barricade E, because of the small number of parts (two), required almost no erection instructions. The only tools needed for erection were the special hand tools included with the barricade package. Erection time for this barricade, not including the installation of the wide-flange steel sections, was 0.53 manhour per linear foot. Considering the placement of the wide-flange sections, the total erection time was 0.70 manhour per linear foot. The various stages in the construction of Barricade E are shown in figure 45.

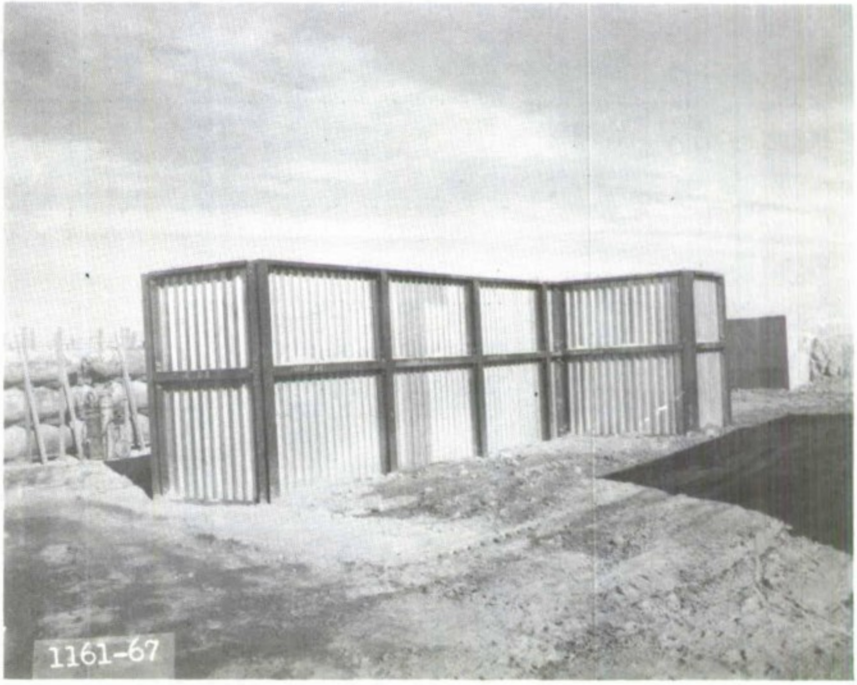
(6) Barricade F

Barricade F was a commercially available steel bin-type barricade** and consisted of five components. The main items were 3-foot wide by 12-foot long side panels and 3-foot wide by 5-foot long transverse panels. Adjacent side panels were overlapped and joined by sliding connecting pins through matching holes. The transverse panels were spaced at 4-foot intervals and

*Kaiser Steel barricade manufactured by Kaiser Steel Corp., Fontana, Calif.
**Republic Steel barricade manufactured by Republic Steel Corp., Youngstown, Ohio.



(a)



(b)

Figure 43. Stages of Construction of Barricade D

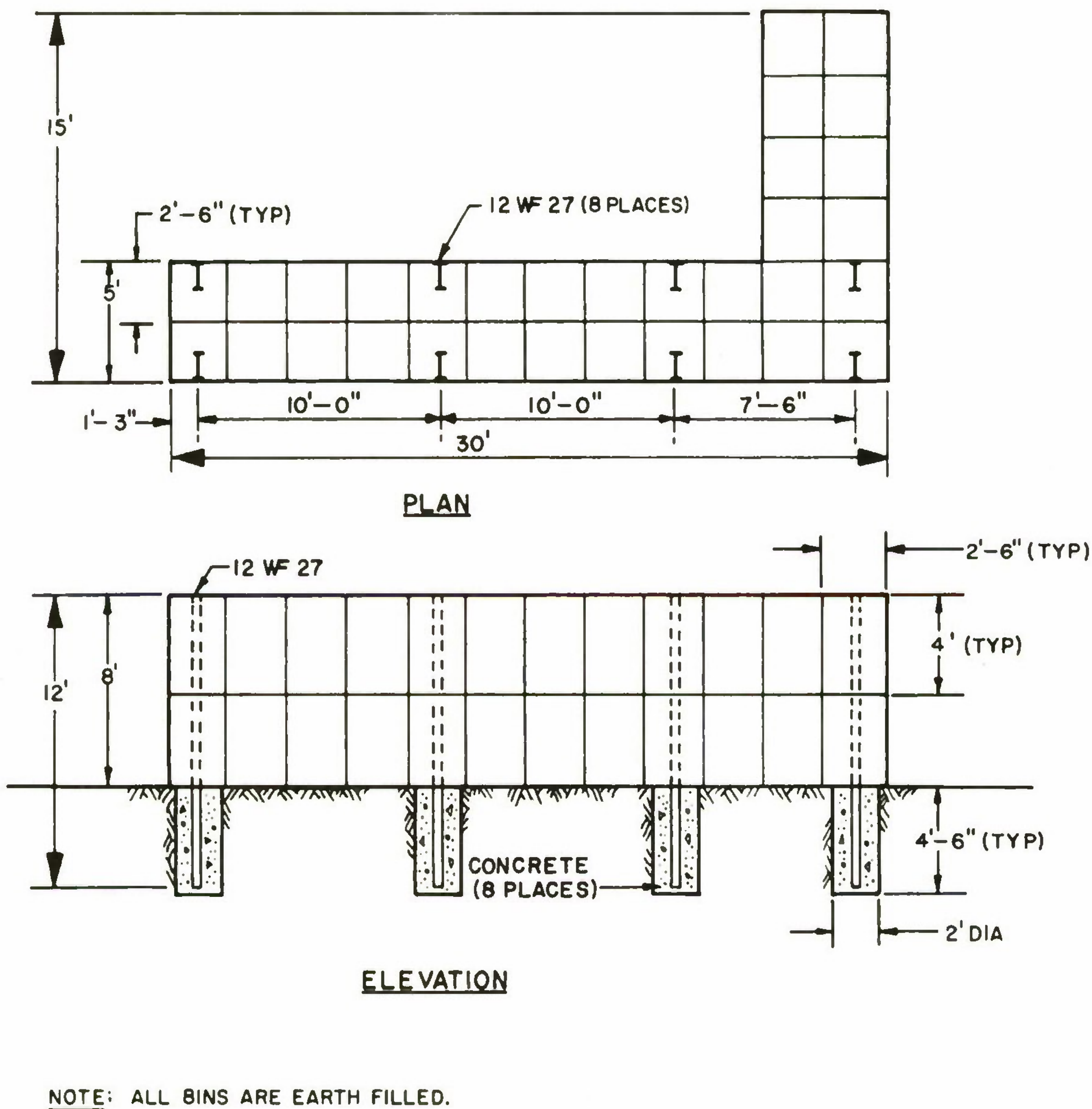
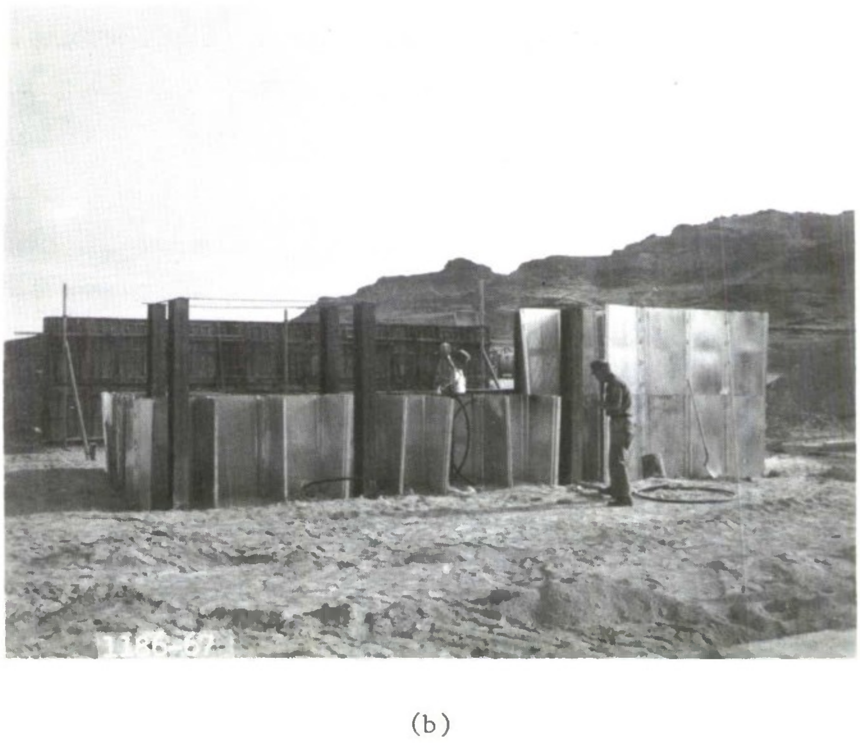


Figure 44. Plan and Elevation of Barricade E

(a)



(b)

Figure 45. Stages of Construction of Barricade E

were also joined to the side panels by connecting pins. Two additional panels were placed on top of the lower panel (either side or transverse) to obtain the required barricade height. A plastic film was placed at the end corners of the barricade to prevent soil leakage. The barricade was 5 feet wide, 9 feet high, and 48 feet long (a 36-foot main section with a 12-foot leg forming a right angle). Figures 46 and 47 show plans and structural details of the barricade and the panel arrangement for Phase III.

This barricade was braced in a similar manner as Barricade E with eight 12WF27 steel sections. No major problems were encountered in the erection. Special hand tools were furnished in the barricade package, and these were the only tools necessary for assembly. However, as before, a small front-end loader was used to lift the wide-flange steel sections into position.

The erection time for Barricade F, not considering the installation of the wide-flange sections, was 0.45 manhour per linear foot. Total erection time, including the installation of the wide-flange sections, was 0.60 manhour per linear foot. Photographs illustrating different stages of construction are shown in figure 48.

A summary of data on the barricade erection is given in table VIII. Figure 49 shows the completed barricades with all instrumentation gages mounted at the mid-height of the barricades.

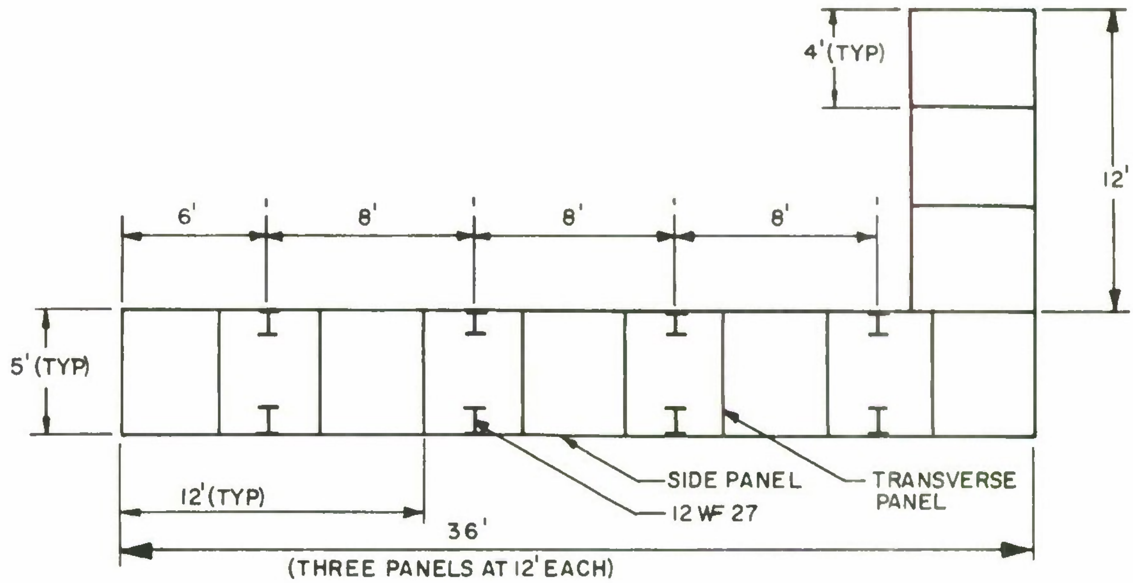
c. Foam-Concrete Simulated Acceptors

(1) Earth Embankments

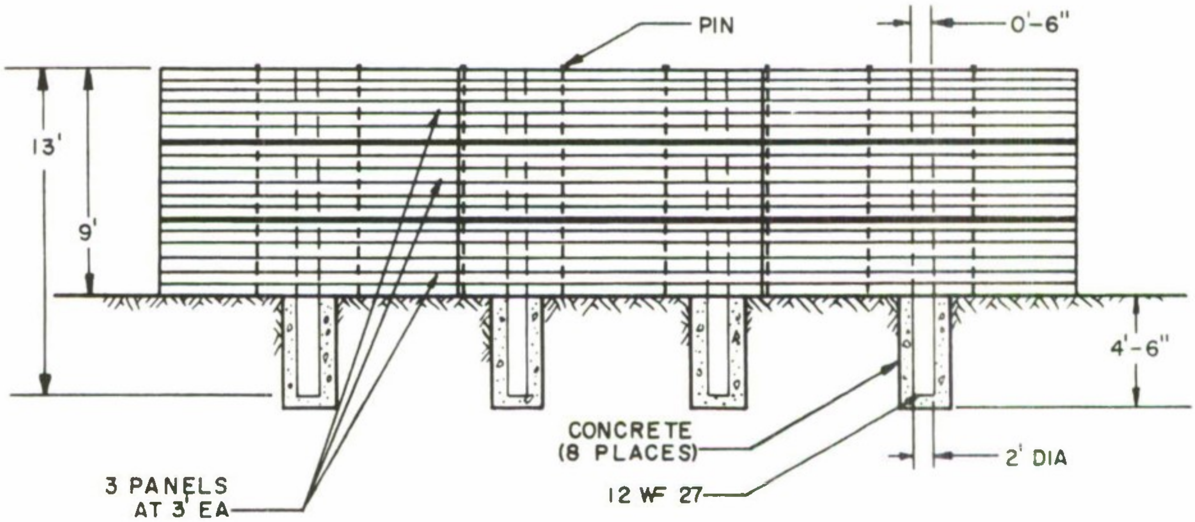
As previously described in Section II, the simulated acceptors directly behind the six barricades were constructed on 5 feet of compacted earth fill. This earth fill was hauled to the acceptor location, spread, and compacted to at least 90 percent of maximum density. After the embankments reached a height of 5 feet above the top of the concrete donor pad, the top surfaces were leveled, and the fronts were shaped to form a 5-foot vertical face.

(2) Forms

Steel forms were used for pouring the foam-concrete acceptors. The forms were removed after the acceptor had cured at least 72 hours.



PLAN



ELEVATION

NOTE: ALL BINS ARE EARTH FILLED.

Figure 46. Plan and Elevation of Barricade F

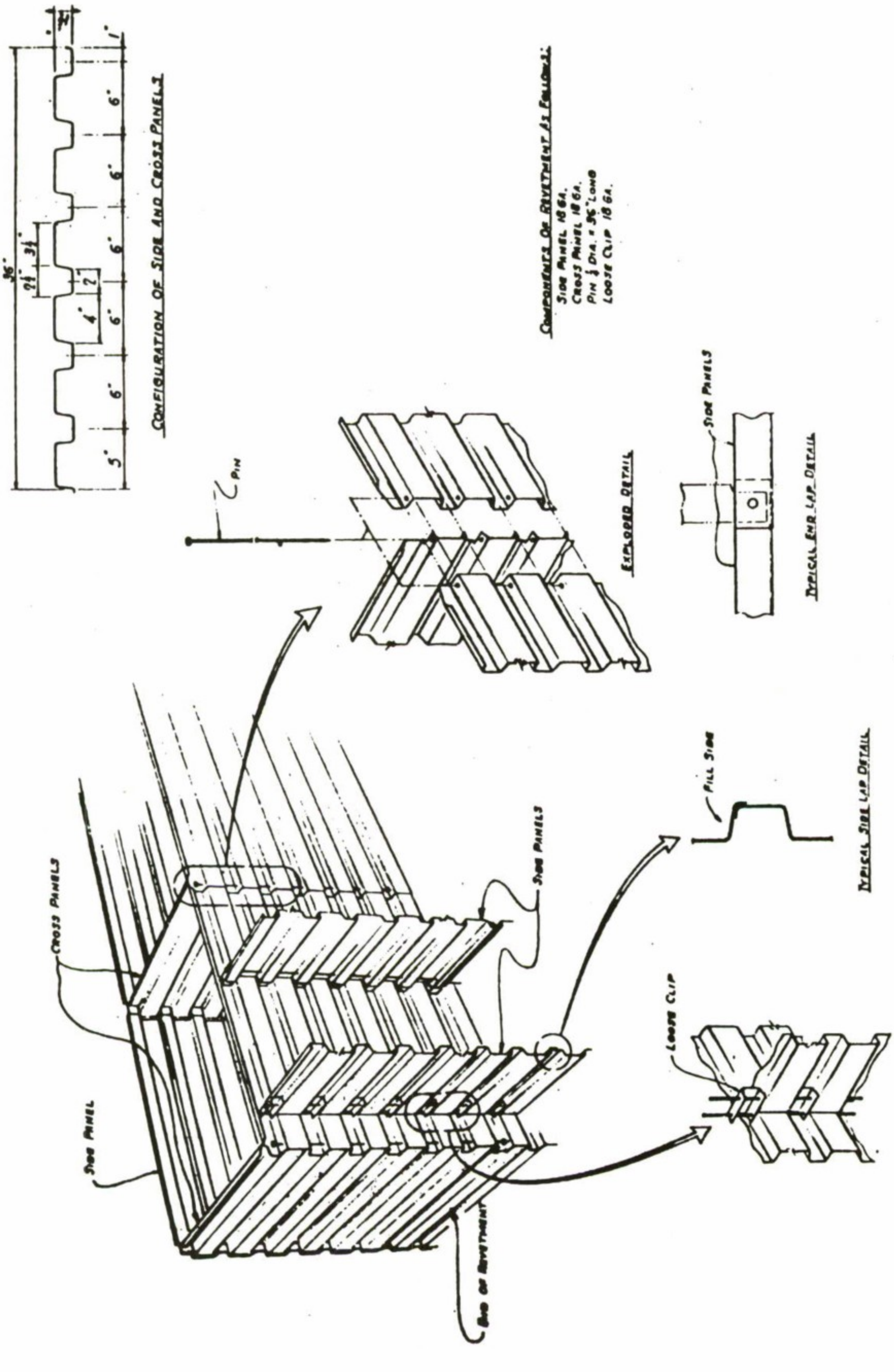
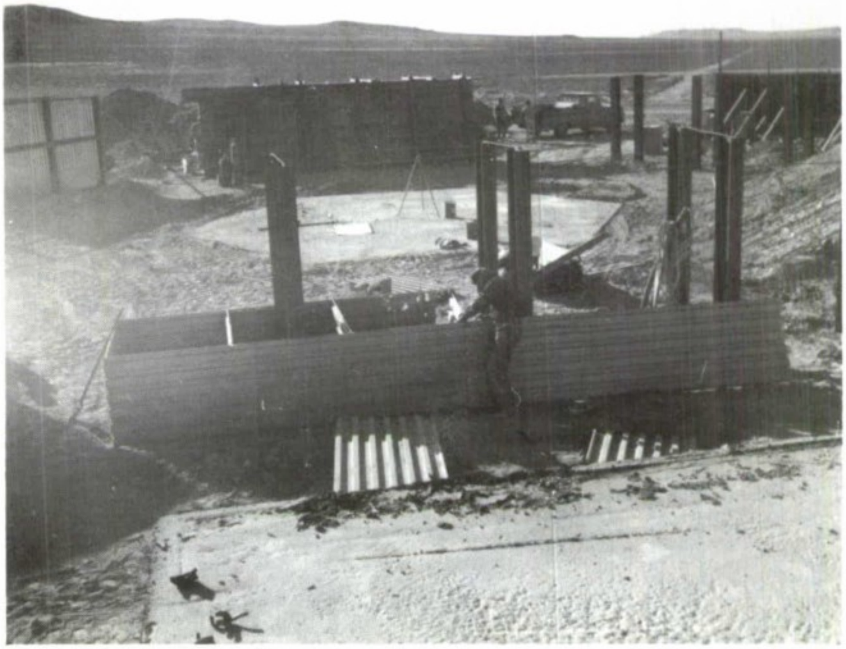


Figure 47. Details of Barricade F



(a)

(b)

Figure 48. Stages of Construction of Barricade F

Table VIII

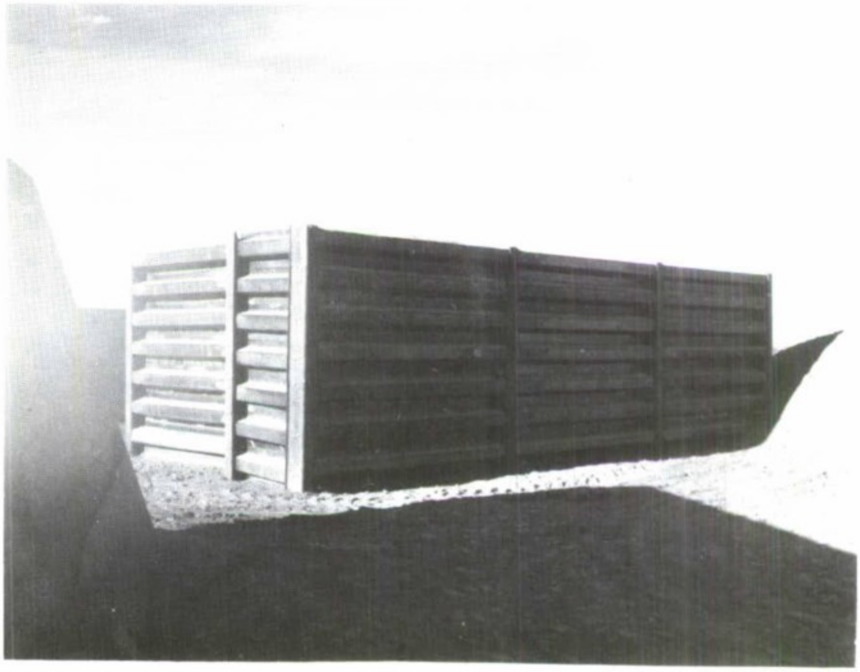
SUMMARY OF BARRICADE ERECTION DATA FOR PHASE III

Barricade	Description	Erection time	Equipment used
A	Local earth compacted to 90 percent max. density	*0.5 mh/lin ft	Front-end loader Steel wheel compactor Hand tampers
B**	Height = 9'4" 40 lin ft Overall width 5'6" (ARMCO)	wo/WF sections 2.26 mh/lin ft w/WF sections 2.41 mh/lin ft	Wrenches, hand Ratchet and socket Small front-end loader used to lift WFs in position
C	Soil cement, Sand = 84 percent Concrete = 8 percent Water = 8 percent	2.02 mh/lin ft 1.18 mh/lin ft additional to erect forms	Crane, 2-3/4-cu-yd buckets, 2-8-cu-yd concrete trucks Portable batch plant
D	AFOCE design, Height = 9'0" 37.5 lin ft Width = 5'0"	1.43 mh/lin ft	Wrenches, hand Ratchet and socket Small front-end loader used to lift WFs in position
E	Height = 8'0" 40 lin ft Width = 5'0" (Kaiser)	wo/WF sections 0.525 mh/lin ft w/WF sections 0.697 mh/lin ft	Small front-end loader to place WFs in position
F	Height = 9'0" 48 lin ft Width = 5'0" (Republic)	wo/WF sections 0.45 mh/lin ft w/WF sections 0.6 mh/lin ft	Small front-end loader to lift WFs in position

*Does not include haul time.

**3-1/2-cu-yd front-end loader used to fill all four metal bin-type barricades plus one operator.

Barricade A



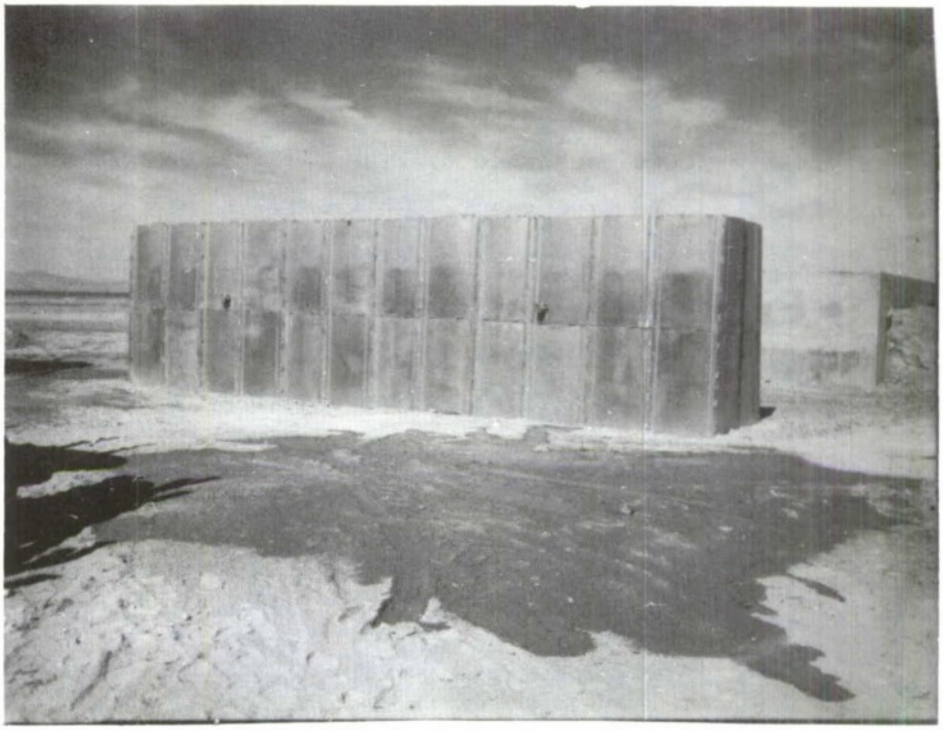
Barricade B

Figure 49. Completed Barricades A, B, C, D, E, and F Showing Air-Pressure Transducer

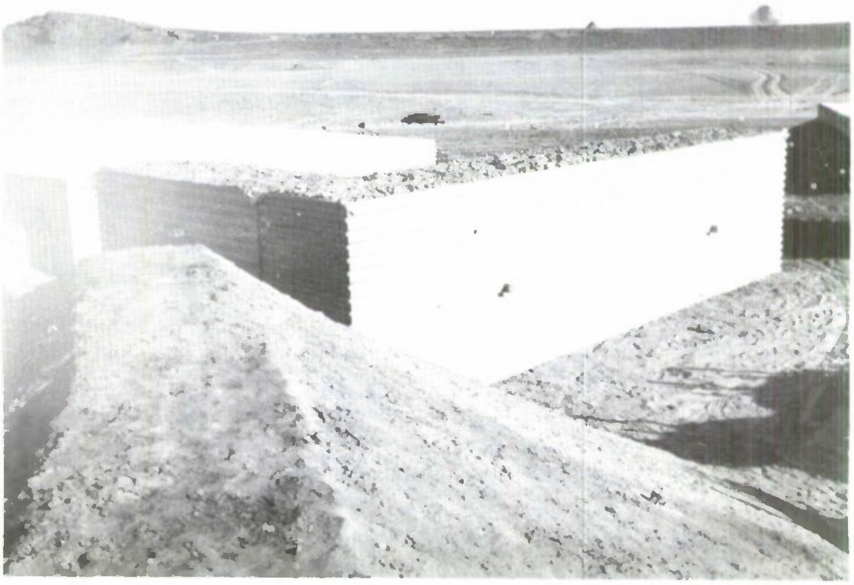
Barricade C

Barricade D

Figure 49 (cont'd). Completed Barricades A, B, C, D, E, and F Showing Air-Pressure Transducer



Barricade E



Barricade F

Figure 49 (cont'd). Completed Barricades A, B, C, D, E, and F Showing Air-Pressure Transducer

(3) Foam Concrete

The design for the foam-concrete mixture is described in Section II. The foam-concrete mixture consisted of Type III (high early strength) portland cement, water, and foaming agent. This material was made by introducing air cells, consisting of a preformed stabilized foam, into the cement-water slurry. The foam was produced in a foam generator in which a liquid foaming agent and water were subjected to compressed air delivered at a predetermined pressure. The foam generator and liquid foaming agent were supplied by a contractor* who specialized in foam concrete. The completed foam-concrete acceptors are shown in figure 50. A portable on-site batch plant was used to proportion and mix the ingredients for the foam concrete.

d. Construction of the Donor Pad

The reinforced-concrete donor pad for Phase III was hexagonal 17 feet 4 inches on each edge and 8 inches thick. The pad contained 1/2-inch diameter steel reinforcing bars spaced at 12 inches center to center in both directions and placed 3 inches below the surface of the slab. The pad was divided into six triangles extending from the center of the pad to the six corners. The external edge of each of these triangles faced a barricade, and each triangle contained the same amount of explosives. The bombs in each triangle were oriented in the same manner to insure that each barricade was exposed to equal pressure and fragments (figure 14).

4. RESULTS

a. Barricade Response

The Phase III detonation completely destroyed all six barricades, and the resulting crater extended approximately 10 feet into the six surrounding foam-concrete simulated acceptors. The remaining portions of the six simulated acceptors were covered with soil, barricade material, and chunks of foam concrete of various sizes. All of the soil and debris were removed from the front and top surfaces of these acceptors so they could be examined.

It appeared that the soil composing Barricade A (standard earth barricade) completely buried simulated acceptor A1 to a depth of about 4 feet. All

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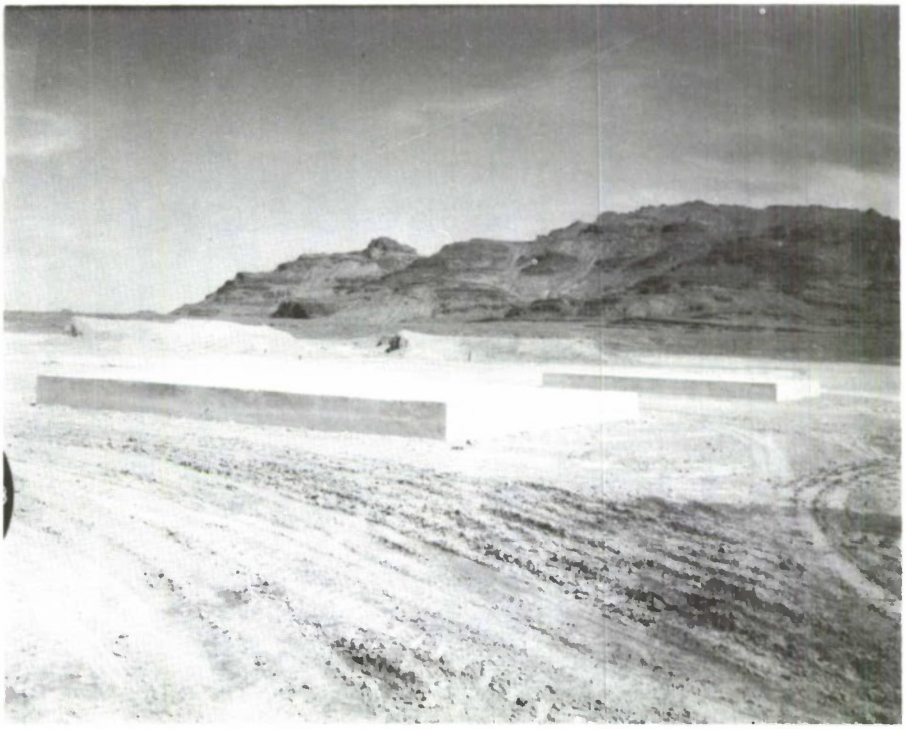
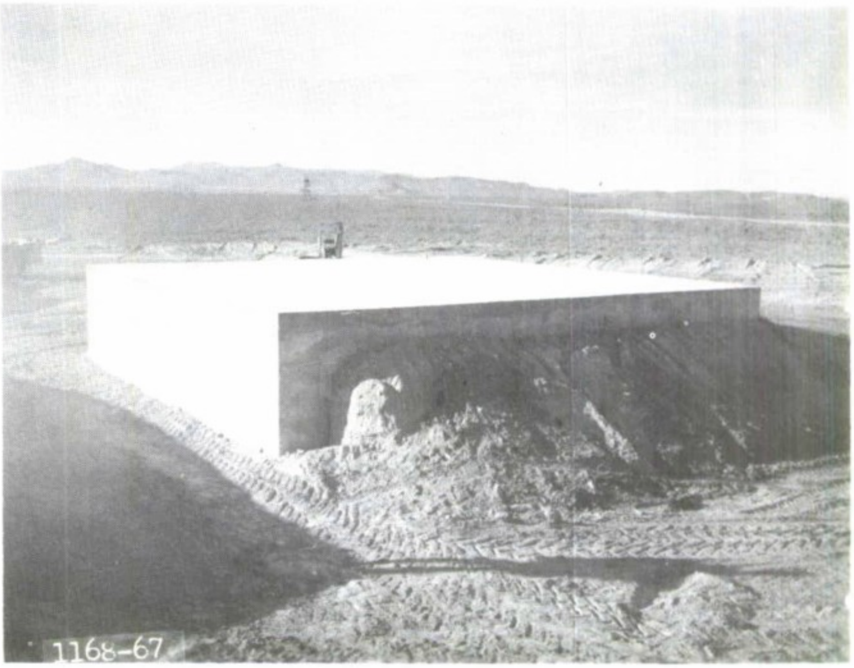
*Aerofill Concretes, South El Monte, California.



(a)



(b)

Figure 50. Typical Foam-Concrete Simulated Acceptors

of this soil was removed from this surface, but very few primary fragments (pieces of bomb casing) were found in the debris. This barricade reacted in the same manner as in Phases I and II. Where bomb stacks were employed as acceptors (as in Phases I and II), bombs rolled outward to some extent with the force of the explosion. In Phase III the simulated acceptor of foam concrete represented a relatively immovable mass as far as horizontal motion was concerned.

Barricade B (Armco metal bin) had several of its components buried near the front of simulated acceptor B1. Also badly distorted barricade stringers, spacers, and columns were found approximately 20 feet behind B1 (see figure 51). A 12WF27 steel beam with the base still partially embedded in concrete and standing upside down (concrete in the air) was located about 10 feet from B1. Another one of these steel sections was found approximately 80 feet from the barricade location in a direction directly behind B1. This section had sheared from the top of its concrete footing. A visual observation of the area behind B1 revealed many small pieces of secondary fragments (barricade components) out to a distance of approximately 800 feet from the original location of Barricade B.

Several large chunks of soil-cement from Barricade C (soil-cement barricade) were found behind simulated acceptor C1. This acceptor was also covered with about 3 feet of soil and small chunks of soil-cement. Debris was removed from the surface, but very few primary fragments were found.

Components of Barricade D (AFOCE metal bin) were found out to a distance 1000 feet behind acceptor D1. Such secondary fragments as clip angles, nuts, bolts, siding, and girt members were found. Three of the concrete footings were found within a distance of 50 feet from simulated acceptor D1. These footings, for the most part, were relatively intact. However, a portion of the six WF15.5 steel column members remained on two of the footings (see figure 52) while the other column had sheared flush with the top of the footing.

Many 4 by 2.5-feet 18-gage sections from Barricade E (Kaiser metal bin) were found spread out to a distance of up to 500 feet from the original location of this barricade. Also several wide-flange sections were found up to a distance of approximately 800 feet. When compared with the

Figure 51. Portion of Barricade B Located Behind Simulated Acceptor B1

Figure 52. Portion of Barricade D Located Near Simulated Acceptor D1

number of heavier and larger secondary fragments from Barricades B and D, this barricade produced only a small amount of secondary fragments. Figure 53 shows a closeup of a 12WF27 steel beam section and its position in relation to the crater; this is approximately 800 feet from acceptor E1.

Barricade F (Republic metal bin) acted in a similar manner to Barricade E regarding secondary fragments. A badly damaged 24-foot portion of Barricade F was found about 75 feet from simulated acceptor F1 (see figure 54). Beyond this point, very few secondary fragments from this barricade were found. Six 12WF27 steel sections were found approximately 1500 feet directly behind F1. Several of these were filled with holes (see figure 55), and all of them had been sheared from the tops of their concrete footings.

b. Simulated Acceptor Response

The 10 foam-concrete simulated acceptors used in Phase III were cleared of all debris and closely inspected, but no fragment penetration of the foam concrete was detected. Chunks of foam concrete were observed within a 500-foot radius from the donor.

The six acceptors immediately surrounding the donor were severely damaged since the crater extended about 10 feet into them. Some large cracks were found in the surfaces and on the side of the remaining portions of these acceptors (see figure 56). The front portions of the six acceptors were so badly damaged by the cratering and blast effects that it was very difficult to thoroughly examine them for primary fragment embedment. However, since careful and painstaking examination revealed no embedded fragments in any part of any acceptor, it seems reasonable to assume that the barricades were effective in stopping those fragments. Some secondary fragments were found in the debris on top of the acceptors which were behind the four metal bin-type barricades. Figure 57 shows acceptors D1, E1, and F1 after all debris had been cleared.

The four simulated acceptors which were constructed on the natural ground surface were only slightly damaged. Acceptors A2 and A3, located directly behind acceptor A1, had practically no debris on them after the detonation. With the exception of some small cracks, very little damage occurred to acceptors A2 and A3. Some primary fragments were found on these acceptors, but they were not considered significant. No secondary fragments were found on acceptors A2 and A3.

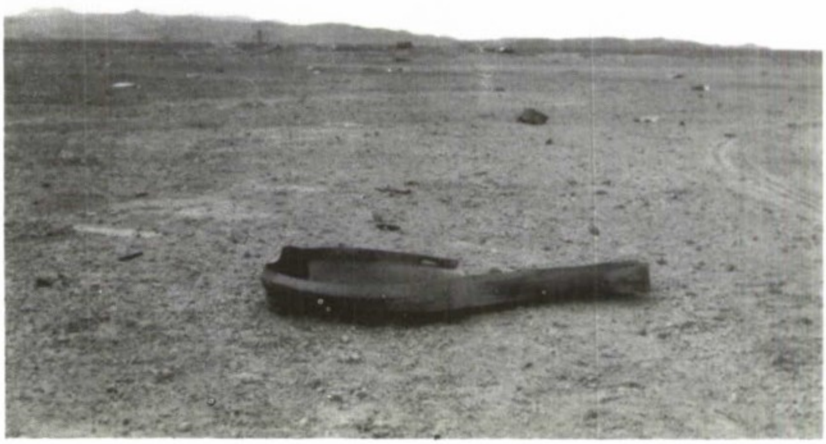


Figure 53. 12WF27 Steel Section Located Approximately
800 Feet from Simulated Acceptor E1

Figure 54. Portion of Barricade F Located about 75 Feet from Simulated Acceptor F1

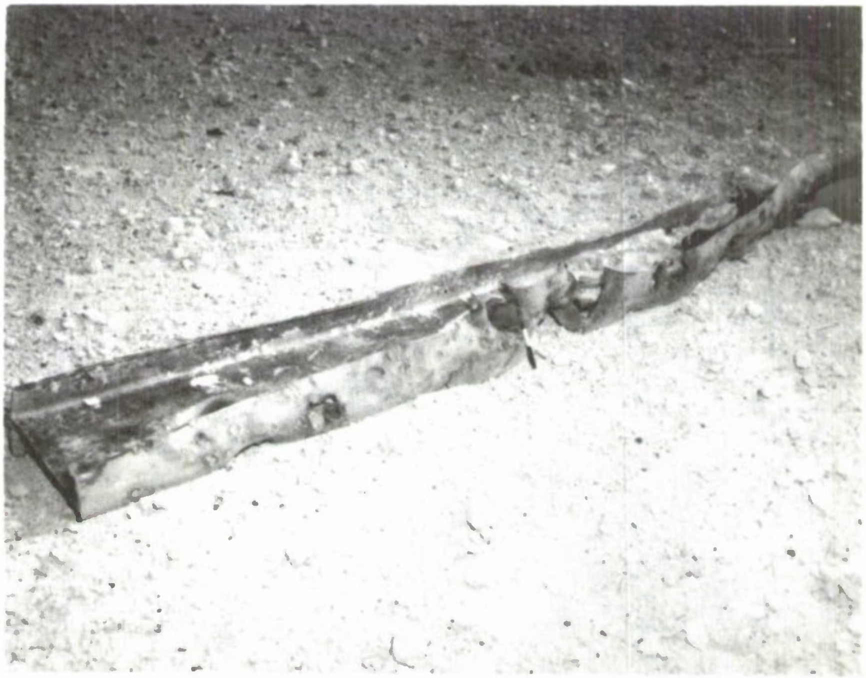


Figure 55. 12WF27 Steel Sections Located Approximately
1500 Feet Behind Simulated Acceptor F1

Figure 56. Typical Large Cracks Found in All Foam-Concrete Simulated Acceptors

Figure 57. Foam-Concrete Simulated Acceptors D1, E1, and F1 after Debris had been Removed

Acceptors D2 and D3, which were located directly behind D1, were each covered with about 18 inches of debris. Most of this debris consisted of soil and small pieces of foam concrete. The damage which occurred to acceptors D2 and D3 was comparable to that of acceptors A2 and A3. All of the debris was removed by hand, and again, some primary and secondary fragments were found lying on top of the acceptors.

c. Instrumentation

An average airblast pressure of 1876 psi was measured at the face of the six barricades. Each barricade responded differently to this loading function, as will be discussed individually later. All structures except Barricade A (the standard earth barricade) responded within 1 millisecond of the arrival of the airblast with both vertical and horizontal motion. Centroidal motion of Barricade A was delayed about 10 msec.

Barricade C (the soil-cement barricade) appeared to be a very rigid structure which transmitted shock to the centroid simultaneously with the arrival of the airblast. The transmitted shock was very high frequency which caused the accelerometers to ring and produce no interpretable data.

All metal bin-type barricades responded similarly with a very rapid initial motion. Barricades B and D had several horizontal oscillations within the first millisecond, after which the transducers were lost. In the case of Barricades E and F, the initial motion was intensive and away from the blast until the transducers were lost. Vertical motion in all four cases consisted of several milliseconds of violent oscillation before the transducers separated from the recording equipment.

d. Fragmentation Survey

The fragmentation survey for Phase III was conducted for both primary (pieces of bomb casing) and secondary (barricade components) fragments. The primary fragments were collected, weighed, and counted in the same manner as in Phases I and II. In addition, measurements of the secondary fragments were taken and reported.

Figure 4 shows the location of each fragmentation survey area used in Phase III, and tables X through XVIII give the results of this survey.

Table IX

RESULTS OF PHASE III PRIMARY FRAGMENTATION SURVEY

Weight interval (pounds)	Number of fragments recovered							
	1N	1S	1E	1W	2N	2S	2E	2W
0-1/4	156	91	160	445	81	111	430	145
1/4-1/2	17	6	16	15	1	9	23	7
1/2-3/4	2	3	12	3	1	1	9	2
2/4-1.0	5	2	7	1	2	3	4	---
1.0-1 1/4	2	2	1	2	1	---	1	---
1 1/4-1 1/2	1	1	---	---	1	---	---	---
1 1/2-1 3/4	---	---	4	---	---	1	---	---
1 3/4-2.0	---	---	1	---	---	---	---	---
2.0-2 1/4	---	---	---	---	---	---	---	---
2 1/4-2 1/2	---	---	---	---	---	---	1	---
2 1/2-2 3/4	---	1	---	---	---	---	---	---
2 3/4-3.0	---	---	---	---	---	---	---	---
3.0-3 1/4	---	---	---	---	---	---	3	---
3 1/4-3 1/2	---	---	---	---	---	---	---	---
3 3/4-4.0	---	---	1	---	---	---	---	---
5 1/4-5 1/2	---	---	---	---	1	---	---	---
6 1/4-6 1/2	2	---	---	---	---	---	---	---

Table IX (cont'd)

RESULTS OF PHASE III PRIMARY FRAGMENTATION SURVEY

Weight interval (pounds)	Number of fragments recovered 3N	3S	3E	3W	4N	4S	4E	4W
0-1/4	30	115	53	30	17	36	14	6
1/4-1/2	4	8	7	3	5	10	3	1
1/2-3/4	2	3	4	2	2	1	---	---
3/4-1.0	1	---	1	---	---	---	---	1
1.0-1 1/4	---	1	2	---	---	---	---	---
1 1/4-1 1/2	---	---	1	---	---	---	---	---
1 1/2-1 3/4	---	---	---	---	---	1	---	---
1 3/4-2.0	---	---	---	---	1	---	---	1
2.0-2 1/4	---	---	---	---	---	---	---	---
2 1/4-2 1/2	---	---	1	---	---	---	---	---
2 1/2-2 3/4	---	---	1	---	---	---	---	---
2 3/4-3.0	---	---	---	---	---	---	---	---
3.0-3 1/4	---	---	---	---	---	---	---	---
3 1/4-3 1/2	---	---	---	---	---	---	---	---
3 3/4-4.0	---	---	---	---	---	---	---	---
5 1/4-5 1/2	---	---	---	---	---	---	---	---
6 1/4-6 1/2	---	---	---	---	---	---	---	---

Table X

RESULTS OF PHASE III SECONDARY FRAGMENTATION SURVEY:

SURVEY AREA 1 EAST

Weight (lb)	Size (inches)	Description
0.01	7/8 x 1	Barricade
0.01	5/8 x 1 1/2	Barricade
0.02	1 x 2 1/8	Barricade
0.02	1 1/8 x 1 5/8	Barricade
0.02	7/8 x 2	Barricade
0.03	1 1/2 x 2 1/2	Barricade
0.03	3/4 x 3 1/4	Barricade
0.03	1 1/4 x 2 1/8	Barricade
0.03	7/8 x 1 3/4	Barricade
0.04	2 x 2 3/4	Barricade
0.04	1 3/8 x 2 7/8	Barricade
0.05	1 3/8 x 3	Barricade
0.05	2 1/4 x 2 1/2	Barricade
0.05	1 1/8 x 2	Barricade
0.06	1 1/8 x 3	Barricade
0.06	2 1/8 x 2 5/8	Barricade
0.10	2 3/8 x 6	Barricade
0.11	2 3/8 x 3 3/4	Barricade
0.12	3 3/4 x 4	Barricade
0.12	2 1/8 x 4 1/2	Barricade
0.13	2 1/4 x 4	Barricade
0.14	2 1/8 x 2 3/8	Barricade
0.17	2 1/2 x 4 1/2	Barricade
0.28	4 1/4 x 5	Barricade
0.29	2 3/4 x 8	Barricade
0.38	5 x 9	Barricade
4.19	1 x 19	Barricade

NOTE: All of the pieces reported above were very badly bent.

Table XI

RESULTS OF PHASE III SECONDARY FRAGMENTATION SURVEY:

SURVEY AREA 1 WEST

Weight (gm)	Size (inches)	Description
1	1/2 x 1 1/2	Barricade
1	3/8 x 7/8	Barricade
1	5/8 x 3/4	Barricade
1	13/16 x 7/8	Barricade
1	1/2 x 5/8	Barricade
1	1/2 x 3/4	Barricade
1	1/2 x 13/16	Barricade
1	3/8 x 7/8	Barricade
1	1/2 x 3/8	Barricade
1	3/8 x 5/8	Barricade
1	1/2 x 5/8	Barricade
1	1/4 x 3/4	Barricade
2	1/2 x 1 1/4	Barricade
2	5/8 x 1 1/8	Barricade
2	3/4 x 15/16	Barricade
2	3/4 x 1 1/8	Barricade
2	5/8 x 7/8	Barricade
2	3/4 x 1 1/4	Barricade
2	1/2 x 1	Barricade
2	5/8 x 1 1/4	Barricade
2	1/2 x 15/16	Barricade
2	3/4 x 7/8	Barricade
2	5/8 x 3/4	Barricade
3	5/8 x 1	Barricade
3	3/4 x 1	Barricade
3	7/8 x 1 1/4	Barricade
4	3/4 x 1 1/2	Barricade
4	5/8 x 1 1/4	Barricade
4	3/4 x 1	Barricade
4	5/8 x 1 1/8	Barricade

Table XI (cont'd)

Weight (gm)	Size (inches)	Description
4	7/8 x 1	Barricade
4	3/4 x 1 3/4	Barricade
4	3/4 x 1 7/8	Barricade
4	1/2 x 1 1/4	Barricade
4	7/8 x 1	Barricade
4	1 x 1 1/4	Barricade
(lb)		
0.01	1 x 1 1/4	Barricade
0.01	1 x 1 1/4	Barricade
0.01	7/8 x 1 3/8	Barricade
0.01	1 x 2	Barricade
0.01	1 1/8 x 1 1/4	Barricade
0.01	1 1/8 x 1 1/2	Barricade
0.01	1 1/8 x 1 5/8	Barricade
0.01	5/8 x 1 1/2	Barricade
0.01	1 1/4 x 1 1/4	Barricade
0.01	1/2 x 1 1/2	Barricade
0.02	1 x 1 5/8	Barricade
0.02	1 1/4 x 1 1/2	Barricade
0.02	1 1/8 x 1 1/4	Barricade
0.02	1 1/8 x 1 3/4	Barricade
0.02	1 1/4 x 1 1/2	Barricade
0.02	7/8 x 1 7/8	Barricade
0.02	1 1/4 x 1 1/4	Barricade
0.02	1/2 x 1 5/8	Barricade
0.02	3/4 x 1 3/4	Barricade
0.02	1 1/4 x 1 7/8	Barricade
0.02	1 1/4 x 1 3/8	Barricade
0.03	1 1/2 x 1 3/8	Barricade
0.03	1 1/4 x 1 5/8	Barricade
0.03	1 1/4 x 1 7/8	Barricade
0.03	1 1/2 x 1 3/4	Barricade

Table XI (cont'd)

Weight (lb)	Size (inches)	Description
0.03	1 1/8 x 2 3/8	Barricade
0.03	1 3/8 x 1 3/4	Barricade
0.04	1 1/8 x 2 1/8	Barricade
0.04	1 x 2 3/4	Barricade
0.04	1 1/2 x 3 3/8	Barricade
0.04	1 7/8 x 2 7/8	Barricade
0.04	1 3/4 x 2 1/8	Barricade
0.04	1 1/4 x 3 1/4	Barricade
0.05	1 7/8 x 2 5/8	Barricade
0.05	2 x 3 1/2	Barricade
0.05	1 1/2 x 2 5/8	Barricade
0.05	2 x 3 1/2	Barricade
0.06	1/4 x 3 7/8	Rod
0.06	1 3/4 x 3	Barricade
0.06	1 3/4 x 2 7/8	Barricade
0.06	1 7/8 x 2 1/2	Barricade
0.07	1 3/4 x 2	Barricade
0.07	1 1/2 x 3 7/8	Barricade
0.07	1 1/2 x 4 1/4	Barricade
0.07	2 3/8 x 3 3/4	Barricade
0.13	2 x 4 3/4	Barricade
0.18	4 1/8 x 4 1/2	Barricade
0.91	9 x 13 1/4	Barricade

Table XII

RESULTS OF PHASE III SECONDARY FRAGMENTATION SURVEY:

SURVEY AREA 1 NORTH

Weight (gm)	Size (inches)	Description
1	1/2 x 15/16	Barricade
1	1/2 x 7/8	Barricade
1	3/8 x 3/4	Barricade
1	1/2 x 3/4	Barricade
4	3/4 x 1 1/8	Barricade
4	1 x 1 1/8	Barricade
4	7/8 x 1 1/8	Barricade
4	1 1/8 x 1 1/4	Barricade
4	3/4 x 1 1/4	Barricade
4	13/16 x 1 1/4	Barricade
4	1/2 x 1 1/8	Barricade
4	7/8 x 1 5/8	Barricade
5	1 1/16 x 1 1/8	Barricade
5	1 1/4 x 1 3/8	Barricade
5	13/16 x 1 1/4	Barricade
5	15/16 x 1 1/2	Barricade
6	1 3/8 x 2	Barricade
6	7/8 x 1 1/4	Barricade
6	7/8 x 1 5/8	Barricade
6	1 1/8 x 1 1/8	Barricade
6	15/16 x 1 1/2	Barricade
6	1 1/8 x 1 3/8	Barricade
7	7/8 x 1 7/8	Barricade
7	1/2 x 2 1/8	Barricade
(lb)		
0.02	1 1/8 x 1 13/16	Barricade
0.02	7/8 x 2 1/2	Barricade
0.02	2 1/2 x 2 5/8	Barricade
0.03	7/8 x 2 3/4	Barricade

Table XII (cont'd)

Weight (lb)	Size (inches)	Description
0.03	7/8 x 1 1/2	Barricade
0.03	1 7/8 x 2	Barricade
0.03	1 5/8 x 2 3/8	Barricade
0.03	1 1/2 x 1 7/8	Barricade
0.03	1 x 2 1/2	Barricade
0.03	2 1/16 x 2 1/4	Barricade
0.04	1 1/2 x 2 5/8	Barricade
0.04	1 5/8 x 2 5/8	Barricade
0.04	1 5/8 x 2 3/4	Barricade
0.04	1 x 3 1/8	Barricade
0.04	2 3/4 x 3	Barricade
0.05	1 7/8 x 2 1/4	Barricade
0.05	1 1/2 x 1 7/8	Barricade
0.05	2 1/4 x 3	Barricade
0.05	2 1/8 x 2 5/8	Barricade
0.05	1 3/8 x 3 3/4	Barricade
0.06	2 3/8 x 2 3/8	Barricade
0.06	2 1/4 x 2 5/8	Barricade
0.09	1 3/8 x 4 1/2	Barricade
0.09	1 7/8 x 3 1/4	Barricade
0.11	2 1/8 x 3 1/8	Barricade
0.11	1 7/8 x 4 5/8	Barricade
0.16	3 1/4 x 4 3/8	Barricade
0.17	2 3/8 x 4 1/8	Barricade
0.58	6 1/4 x 10 1/2	Barricade
2.99	4 1/2 x 1/2	1 each nut and bolt with spacers and clamps

Table XIII

RESULTS OF PHASE III SECONDARY FRAGMENTATION SURVEY:

SURVEY AREA 1 SOUTH

Weight (gm)	Size (inches)	Description
2	1/2 x 7/8	Barricade
(lb)		
0.02	1 5/8 x 1 7/8	Barricade
0.02	3/4 x 1 3/8	Barricade
0.02	1 x 1 1/2	Barricade
0.03	1 7/8 x 2	Barricade
0.03	1 1/8 x 1 3/4	Barricade
0.03	1 1/8 x 2	Barricade
0.04	1 1/2 x 2 1/2	Barricade
0.04	1 3/4 x 2 3/8	Barricade
0.05	1 7/8 x 1 7/8	Barricade
0.06	1 1/2 x 3 1/2	Barricade
0.06	1 3/4 x 2 3/4	Barricade
0.06	2 1/8 x 2 1/16	Barricade
0.07	1/2	Washer
0.07	2 5/8 x 3 1/2	Barricade
0.10	2 x 3 5/8	Barricade
0.10	2 1/4 x 3 7/8	Barricade
0.10	2 1/4 x 2 1/2	Barricade
0.10	2 5/8 x 3 5/8	Barricade
0.11	2 1/8 x 4 1/2	Barricade
0.11	1 7/8 x 4 1/4	Barricade
0.12	3 x 3 5/8	Barricade
0.13	2 1/4 x 4	Barricade
0.13	2 1/4 x 4 1/2	Barricade
0.14	2 7/8 x 4 1/4	Barricade
0.18	1 7/8 x 3 1/2	1/8 inch steel plate
0.25	3 1/4 x 6	Barricade
0.31	3 5/8 x 4 3/4	Barricade

Table XIII (cont'd)

Weight (lb)	Size (inches)	Description
0.32	3 x 4 1/8	Barricade
0.37	3 1/4 x 6	Barricade
0.54	2 1/4 x 7 1/4	Barricade
0.59	5 1/4 x 8 1/8	Barricade
0.64	4 x 6 15/16	Barricade
0.71	3 3/8 x 14 1/8	Barricade
0.73	5 7/8 x 9	Barricade
0.75	5 1/8 x 11 5/8	Barricade
0.77	6 7/8 x 7 3/8	Barricade
1.36	3 7/8 x 9 3/8	1/8 inch steel plate
3.44	13 7/8 x 16 1/2	Barricade

Table XIV

RESULTS OF PHASE III SECONDARY FRAGMENTATION SURVEY:

SURVEY AREA 2 EAST

Weight (gm)	Size (inches)	Description
3	7/8 x 1 1/8	Barricade
4	7/8 x 1 3/8	Barricade
5	7/8 x 1 1/8	Barricade
(lb)		
0.01	7/8 x 1 3/4	Barricade
0.02	1 1/4 x 1 3/8	Barricade
0.02	1 x 1 1/2	Barricade
0.02	7/8 x 2 1/2	Barricade
0.02	1 x 2	Barricade
0.03	1 1/8 x 1 3/8	Barricade
0.03	1 1/4 x 2 1/4	Barricade
0.04	1 3/4 x 2 3/8	Barricade
0.04	1 7/8 x 2 3/16	Barricade
0.05	1 1/4 x 2 1/2	Barricade
0.07	2 1/2 x 3 1/4	Barricade
0.08	1 5/8 x 2 3/4	Barricade
0.08	2 1/8 x 4 1/8	Barricade
0.08	2 1/4 x 2 3/4	Barricade
0.09	2 1/4 x 2 3/8	Barricade
0.10	2 5/8 x 4 1/2	Barricade
0.11	2 3/4 x 4 1/2	Barricade
0.12	2 3/4 x 4 1/4	Barricade
0.14	2 3/8 x 3 5/8	Barricade
0.15		Two washers
0.19	4 3/8 x 4 1/2	Barricade
0.26	4 5/8 x 5 1/4	Barricade
0.28	5 x 5 1/2	Barricade
0.28	4 x 5 1/2	Barricade
0.50	3 1/2 x 6	Barricade

Table XIV (cont'd)

Weight (lb)	Size (inches)	Description
0.50	2 7/8 x 8 1/2	Barricade
0.89	4 3/4 x 10 1/8	Barricade
3.36	2 7/8 x 6	3/8-inch steel angle

Table XV

RESULTS OF PHASE III SECONDARY FRAGMENTATION SURVEY:

SURVEY AREA 2 WEST

Weight (lb)	Size (inches)	Description
0.01	1 1/8 x 1 1/8	Barricade
0.03	1 7/8 x 2 3/8	Barricade
0.05	1 5/8 x 2 1/4	Barricade
0.05	1 1/2 x 1 7/8	Barricade

Table XVI

RESULTS OF PHASE III SECONDARY FRAGMENTATION SURVEY:

SURVEY AREA 2 NORTH

Weight (lb)	Size (inches)	Description
0.01	3/4 x 1 1/2	Barricade
0.01	3/4 x 1 3/8	Barricade
0.01	1 x 1	Barricade
0.02	1 x 1 1/4	Barricade
0.02	1 1/4 x 1 3/8	Barricade
0.03	1 3/8 x 1 3/4	Barricade

Table XVII

RESULTS OF PHASE III SECONDARY FRAGMENTATION SURVEY:

SURVEY AREA 2 SOUTH

Weight (lb)	Size (inches)	Description
2 gm	3/8 x 1	Barricade
0.03	1 1/4 x 1 7/8	Barricade
0.03	1 1/8 x 2	Barricade
0.04	1 3/8 x 1 5/8	Barricade
0.04	1 1/4 x 2 3/8	Barricade
0.05	1 5/8 x 1 3/4	1/4-inch steel plate
0.06	2 1/8 x 3 1/4	Barricade
0.06	1 3/8 x 3 1/8	Barricade
0.07	1 3/4 x 2 5/8	Barricade
0.07	2 3/4 x 2 3/4	Barricade
0.09	2 x 2 3/8	Barricade
0.09	2 1/8 x 2 7/8	Barricade
0.12	2 1/4 x 3 1/8	Barricade
0.13	1 1/2 x 2 7/8	Barricade
0.13	2 5/8 x 4 1/4	Barricade
0.15	2 1/8 x 5 3/8	Barricade
0.21	2 1/2 x 4	Barricade
0.29	3 3/8 x 3 1/2	Barricade
0.33	3 1/4 x 6 3/4	Barricade
0.64	4 7/8 x 8 1/4	Barricade
0.73	2 1/4 x 5 3/8	1/4-inch steel plate
2.40	4 1/8 x 24 1/2	Barricade
3.79	10 x 15 1/4	Barricade
4.42	6 5/8 x 7 1/2	1/4-inch steel plate

e. Crater Data

Cross sections of the Phase III crater were taken every 30° from an assumed north. This angle was chosen in an attempt to get a cross section over every barricade and one between the barricades.

The diameter of the apparent crater measured at the top of the outermost rim ranged from 144 feet to 152 feet. The depth of the crater ranged from 5 feet to 8 feet below the top of the destroyed donor pad. The height of the ejected material at the outermost rim ranged from 4 feet to 11 feet above this reference elevation. These heights varied considerably due to the fact that much of the ejected material rested on top of 7-foot high simulated acceptors.

Figures 58 through 60 illustrate the crater produced by the Phase III detonation (100,000 pounds net weight explosives).

f. Photography

As observed in table IV, three high-speed cameras were used in Phase III. The frame rates for these cameras were increased to 9000 frames per second. Some high-speed 16-mm film strips were obtained showing barricade material and wide-flange steel sections being ejected. However, close-in to the donor, the instant after detonation, nothing could be detected because the fireball flared out detailes on the film. However, general photographic coverage was excellent.

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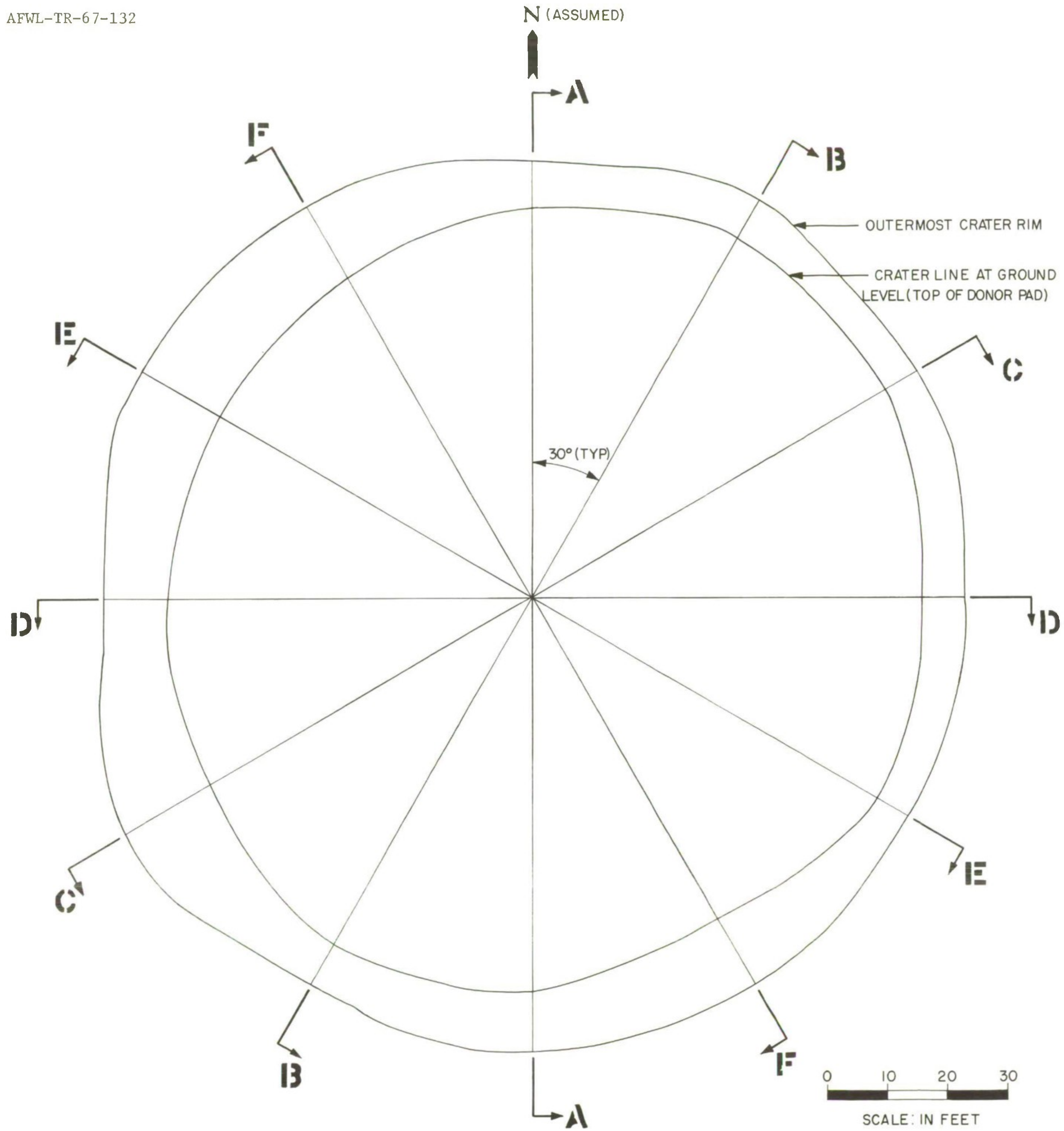


Figure 58. Plan View of Phase III Crater

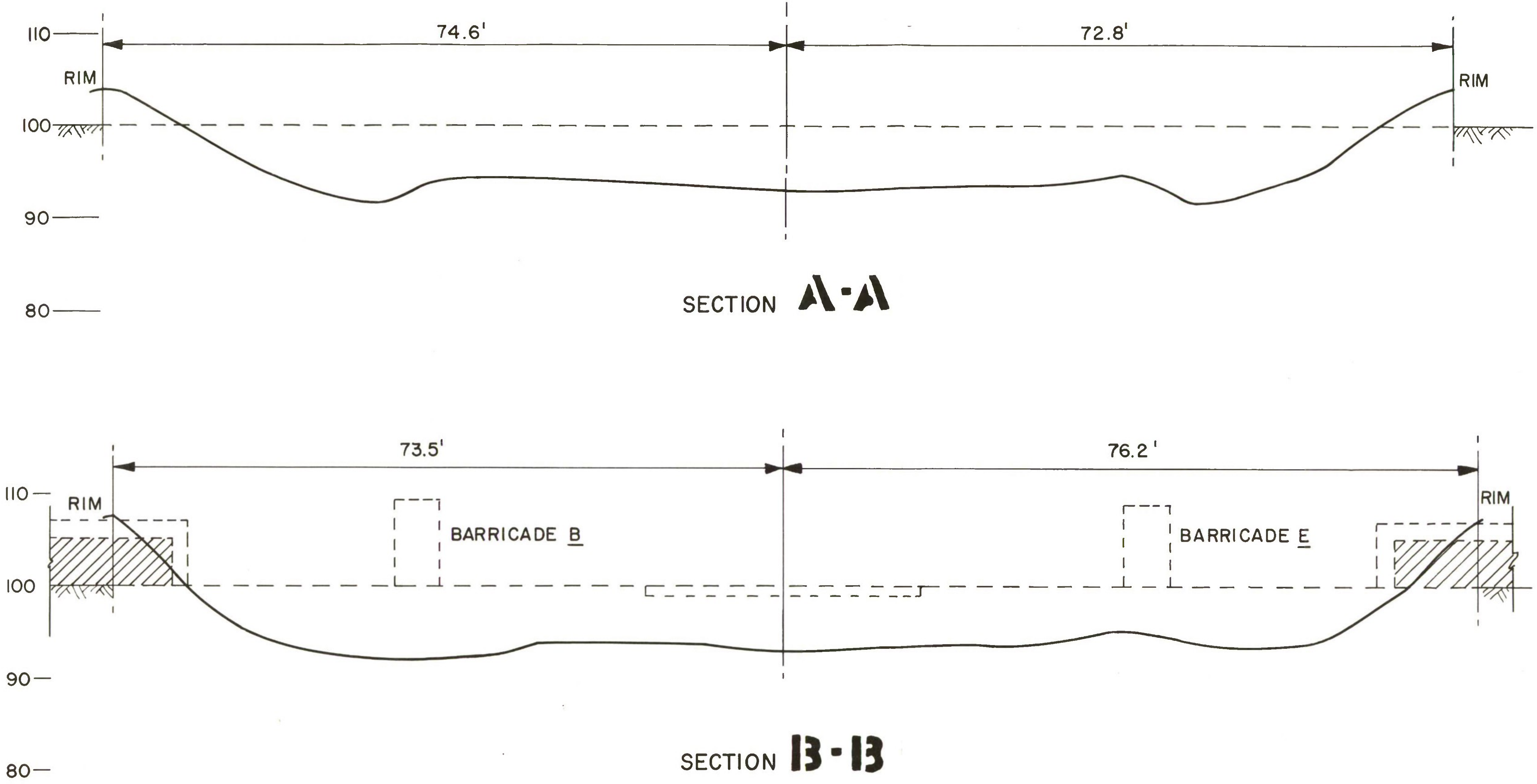


Figure 59. Cross Sections of Phase III Crater

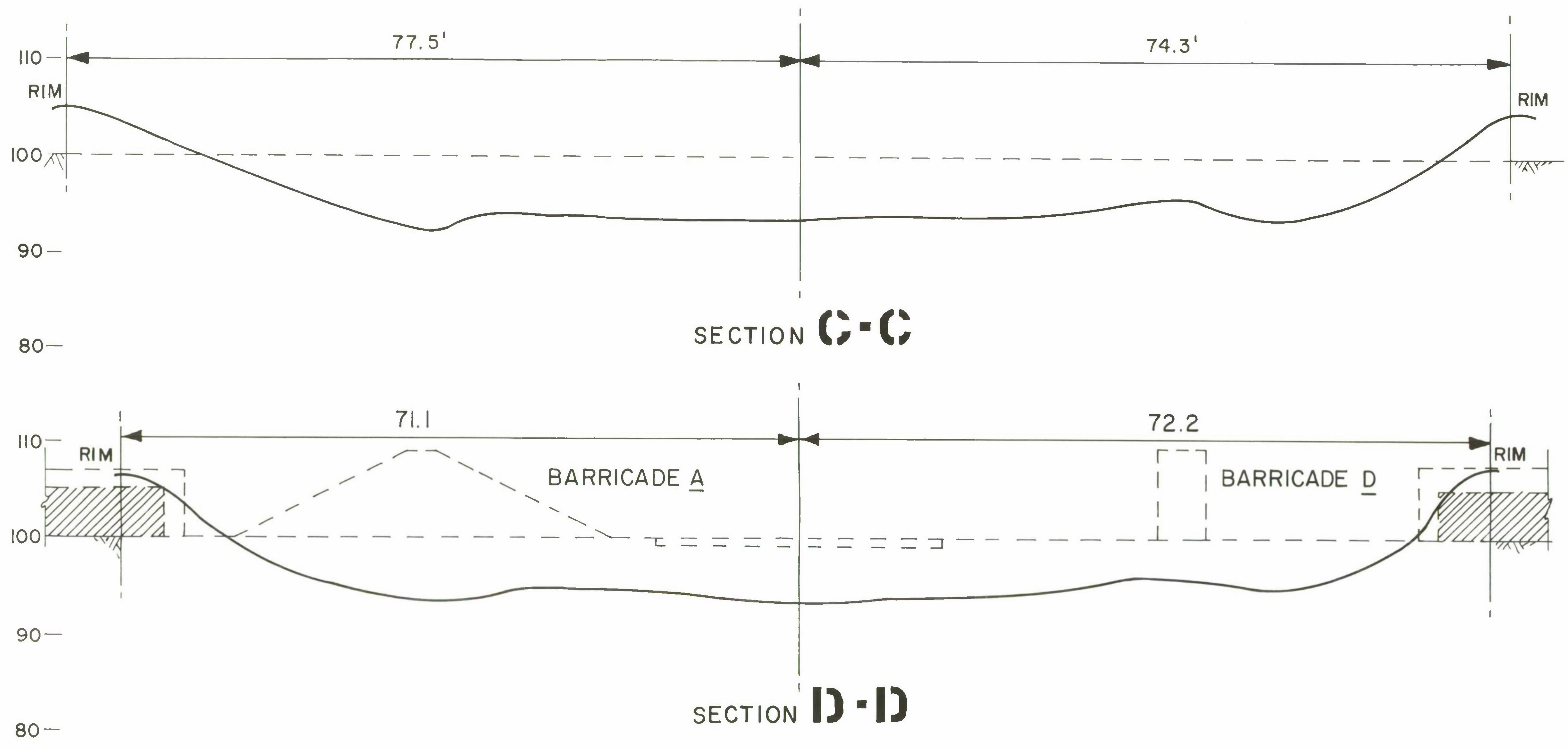


Figure 59.(cont'd). Cross Sections of Phase III Crater

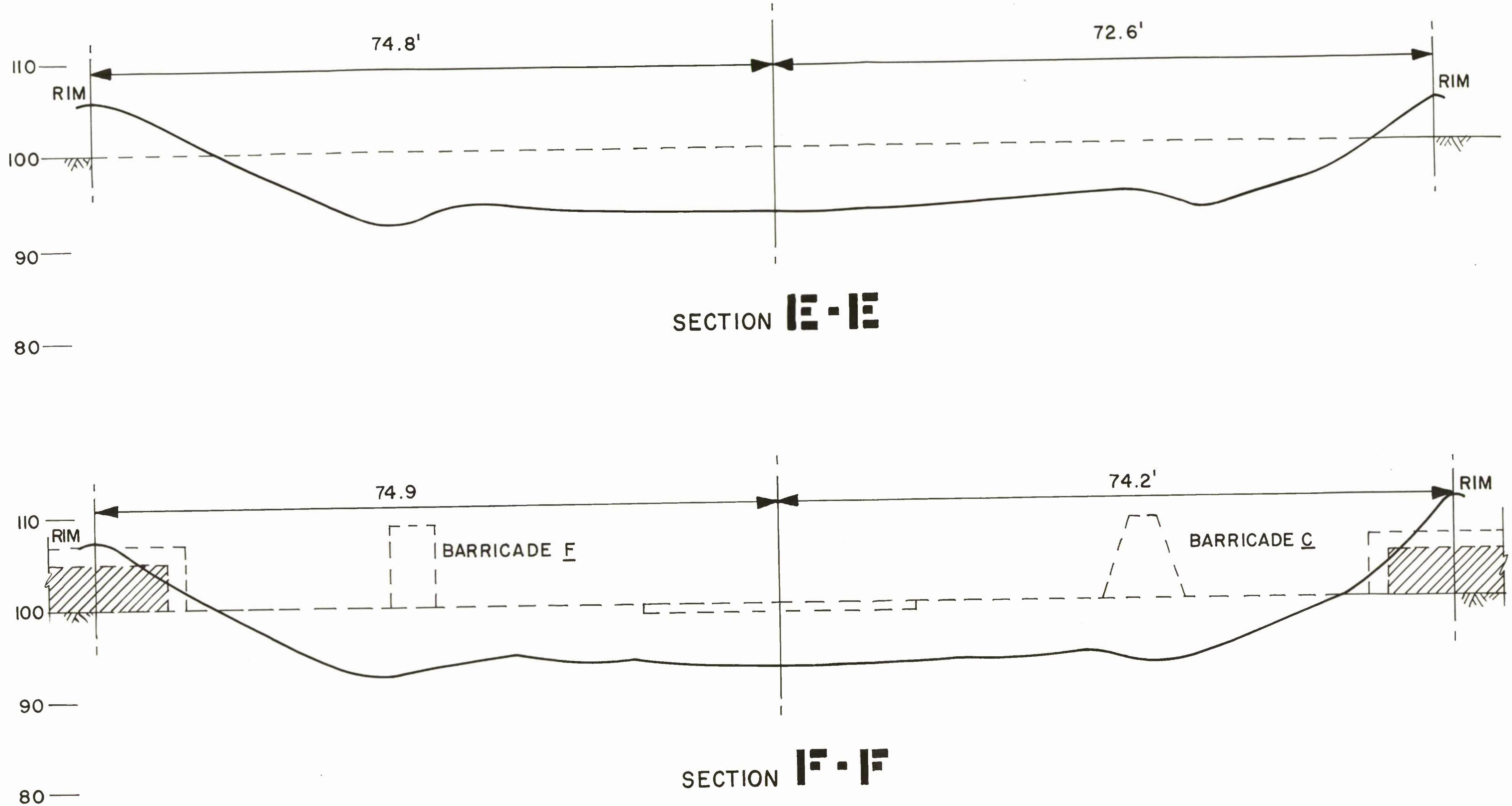


Figure 59 (cont'd). Cross Sections of Phase III Crater

Figure 60. Aerial View of Phase III Crater

SECTION V

PHASE IV

1. GENERAL

The objective of Phase IV was to determine if the detonation of a single bomb of a donor stack would detonate other bombs in the stack and hurl some of the remaining bombs above the barricade to subsequently be detonated and ultimately detonate an acceptor stack by fragment impingement. This phase had no instrumentation measurements; however, complete photographic coverage was provided. A layout of the Phase IV test configuration is shown in figure 61 and preshot and postshot photographs are shown in figures 62 and 63.

Phase IV was fired at 1000 hours (MDT) on 1 September 1967 at Hill AF Test Range, Utah. The site for this phase was located approximately 2500 feet north of the Phase II donor. As previously mentioned, because of this test site location, a new camera station (station number 6) was introduced.

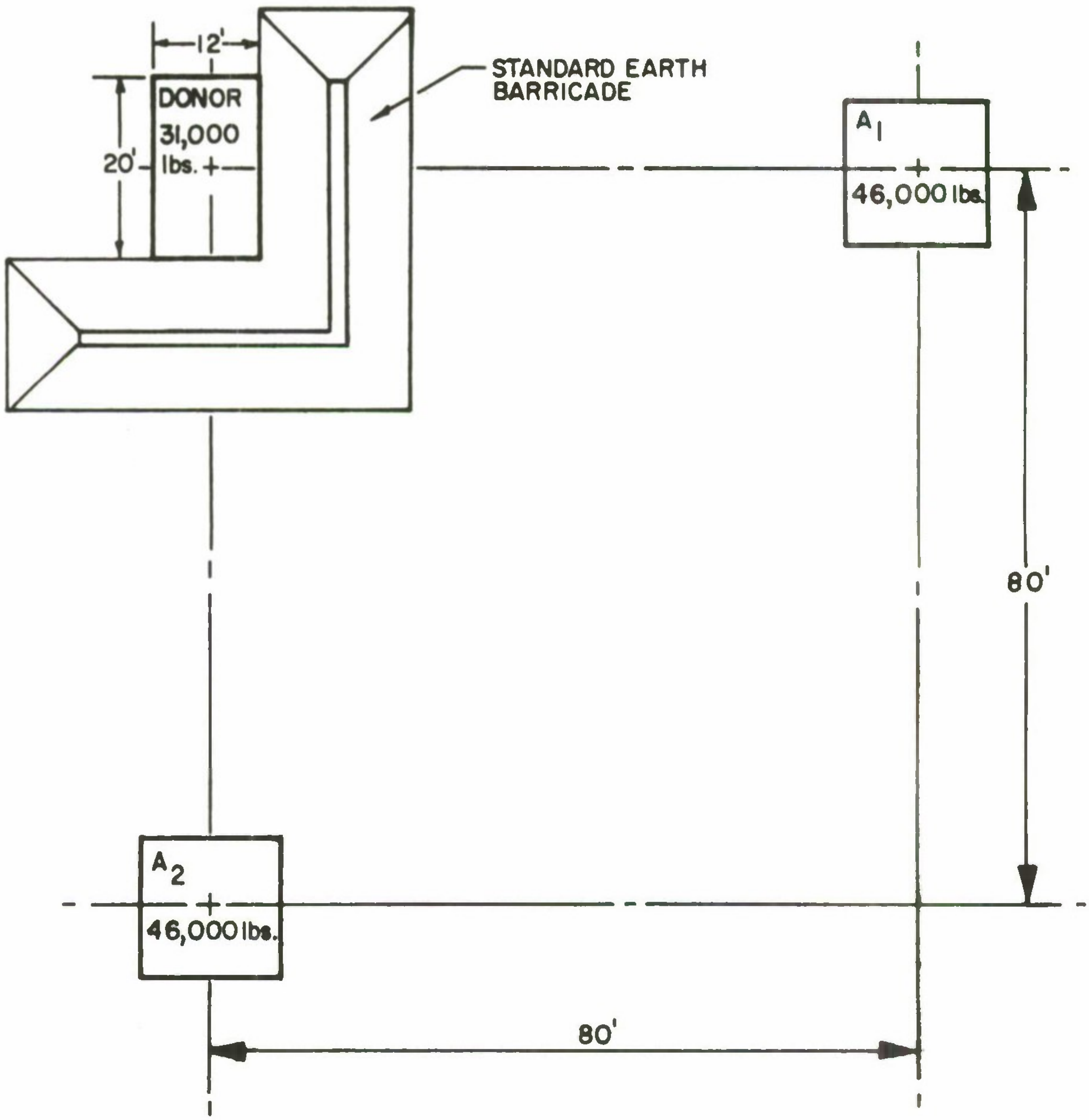
2. DESCRIPTION OF PHASE IV

This phase of the test consisted of a donor bomb stack and two acceptor bomb stacks, all separated by a standard earth barricade. The donor bomb stack consisted of 80 M117 750-pound bombs arranged in two rows, 10 bombs long and four high. These rows were separated by the usual working aisle of about 2 feet, representing normal field practice. The acceptors each contained 39 M66-type 2000-pound bombs spread out in one layer to represent the exposure area that would be presented by adjacent bomb stacks in a storage module. (See figure 15.)

3. CONSTRUCTION PROCEDURES

a. Construction of Earth Barricade

As observed in figures 61 and 62, this earth barricade was L-shaped and was constructed in the same manner and to the same dimensions as those for Phases I and II.



NOTES: 1. Donor is on reinforced concrete.

2. A1 and A2 are on natural ground surface.

3. All weights are net weight explosives.

Figure 61. Test Configuration for Phase IV

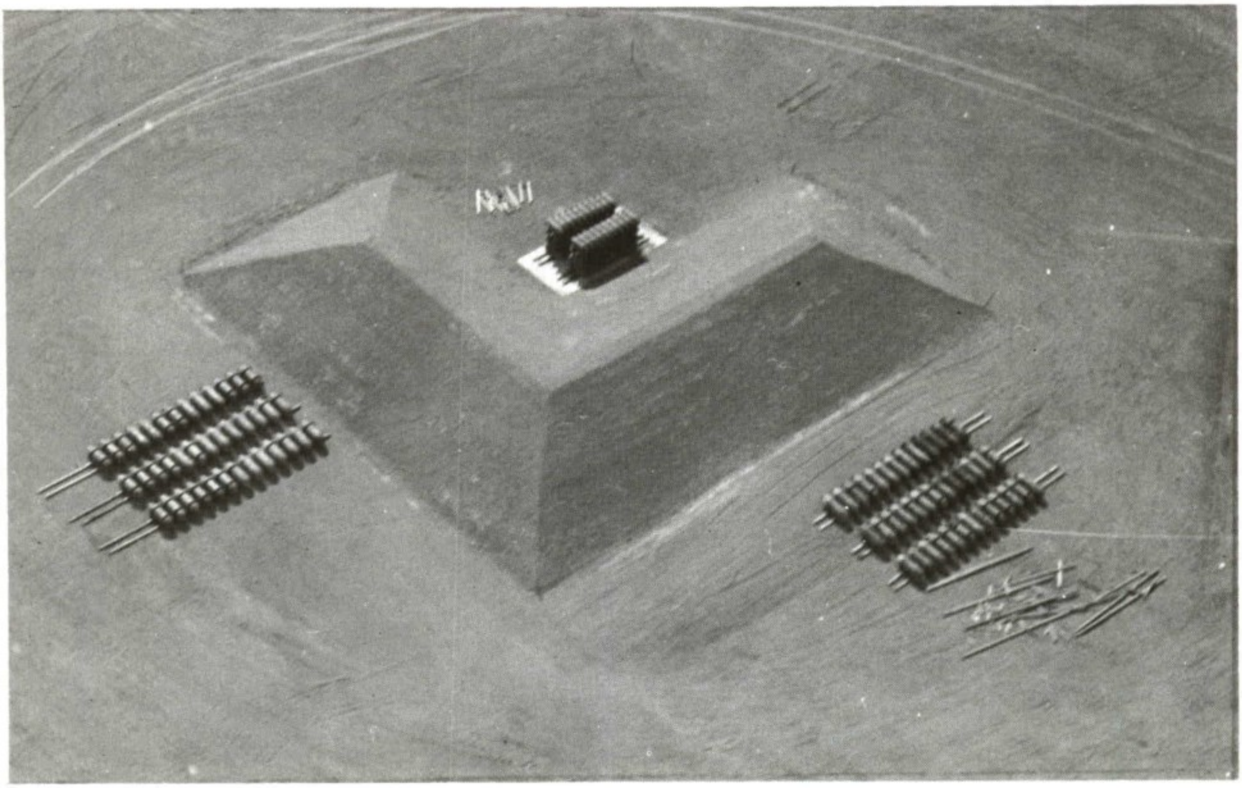


Figure 62. A Preshot Aerial View of Phase IV Configuration

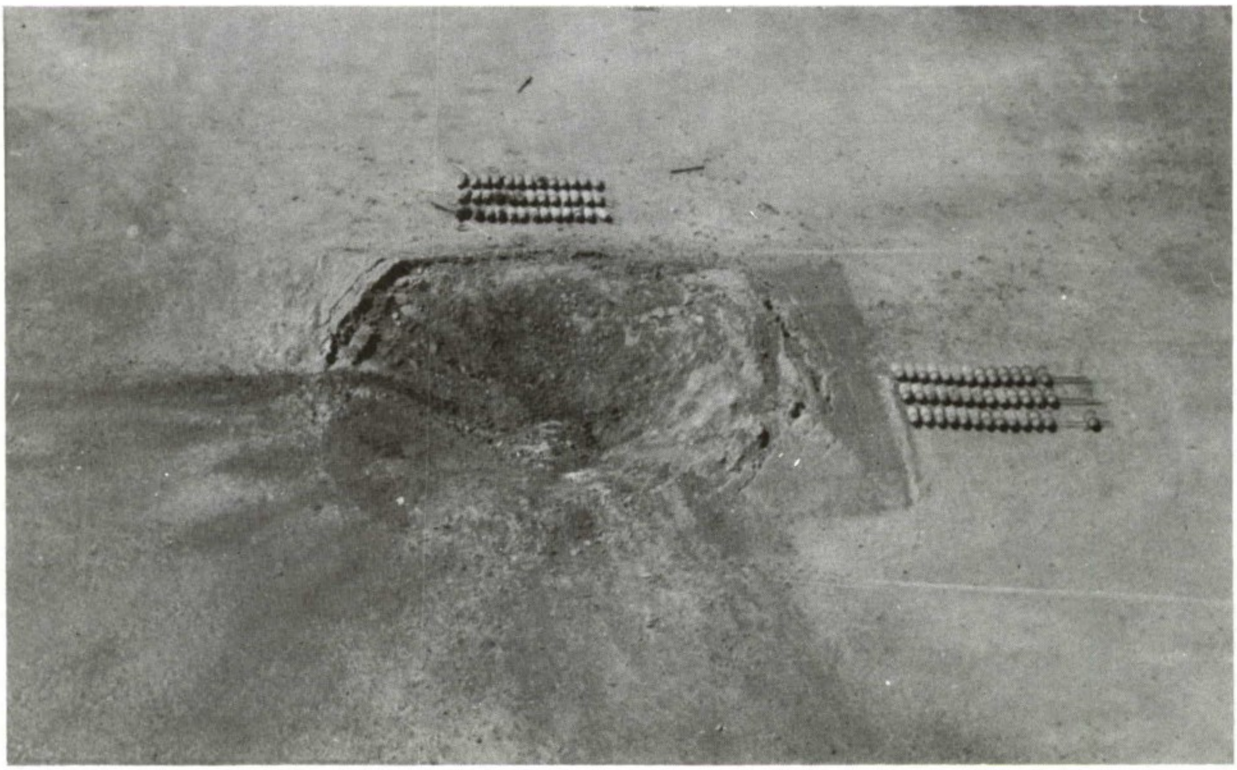


Figure 63. A Postshot Aerial View of Phase IV

b. Construction of Concrete Donor Pad

The donor pad was the only concrete storage pad used in Phase IV. The pad was 12 feet wide by 20 feet long by 9 inches thick, with 1/2-inch diameter steel reinforcing bars spaced at 18 inches center to center in both directions and located 3 inches from the top of the slab. The acceptors for Phase IV were placed on timber dunnage on the ground surface. Figure 16 shows the donor bomb stack and also indicates the bomb which was primed and detonated.

4. RESULTS

a. Donor Reaction

Detonation of the single bomb resulted in near-simultaneous detonation of the entire donor stack. Apparently no bombs were tossed and detonated while in the air.

b. Acceptor Response

The two acceptors were not affected by the detonation of the donor. The acceptors were only one bomb deep, and the bombs shifted only slightly with two end bombs in acceptor A1 rolling off the dunnage onto the ground.

c. Photography

In Phase IV, three high-speed cameras were used. The high-speed cinema films revealed a slight difference between this detonation and the Phase I and Phase II detonations. The film revealed that burning fragments of explosives, dunnage, etc., were projected from the donor in all directions to a greater degree than noted in earlier phases. Although simultaneous detonation (within the broad meaning of the term) apparently occurred, the detonation probably did not propagate through the mass with the degree of rapidity experienced in the nearly instantaneous detonation of donors in Phases I and II. This was due to the fact that only one bomb was primed and detonated in this relatively small donor. No other differences or unusual conditions could be detected. Photographic coverage was very comprehensive.

SECTION VI

DISCUSSION OF RESULTS

Portions of the results of BIG PAPA which were presented briefly in the preceding sections require amplification and correlation. These will be discussed below.

In Phases I and II the air-pressure curves were developed mainly from the surface measurements outside the immediate area of the barricades. Two groups of air-pressure data were found to be consistently different than the resultant smoothed air-pressure curve. These data were the air pressures from the post-mounted frontal measuring transducers and those from transducers located on the leeward side (side away from the donor) of the barricade.

The postmounted transducers measured frontal pressures consistently higher (approximately 60 percent) than the surface pressures for those transducers at fairly large distances from the barricades. Near the leeward side of the barricade, the data were not as consistent, some indicating higher pressures and others indicating lower pressures. This indicated that the barricade apparently perturbated the airblast in its immediate vicinity, but as the front moved away from the detonation, the perturbations were diminished.

An air-pressure decrease at the toe of the barricade on the leeward side was noted. Pressures were about 170 percent below the average pressure curve on the side of the barricade and about 30 percent below at the toe. These measurements were consistently low, indicating that the airblast flow was not uniform over the barricade, but in fact was turbulent, and the major portion of the blast may have bounced from the top of the barricade to some point beyond it before uniform flow again occurred.

The high-speed cinema film of Phases I and II showed the passage of the airblast front over the barricades appearing as a thin sheet of water flowing over the barricades. This was evidenced visually by a dust cloud moving down over the barricade which correlates with the turbulence indicated by the air-pressure measurements.

Turning to the area of acceleration, the comparison of input acceleration to stacks of bombs on concrete storage pads and natural ground indicated that more than twice as much shock energy was delivered through the ground to a stack resting on the ground. This resulted in a much more severe breakdown of the stack and, as indicated by acceptor A5 of Phase I, increased the possibility of incurring bomb damage or sympathetic simultaneous or delayed stack detonation. The larger amount of vertical acceleration in stacks on the ground could also conceivably toss bombs off the stack which could detonate or which could cause a detonation in the stack by falling onto other bombs. The low-order detonation occurring in one bomb in acceptor A5 was thought to have been caused by 2000-pound bombs falling on a 750-pound M117 bomb that had fallen from the stack in precisely the manner suggested above. No evidence of actual tossing of bombs is available, however. An interesting comparison was made between the response of the standard earth barricades in Phases I and III where motion-sensing transducers were available. Both centroidal distances corresponded to a K factor of about 0.55. Centroidal motion was found to lag the incidence of pressure on the barricade face by 10 to 18 milliseconds. This is significant because it indicated that the fragment-absorbing function had sufficient time to be completed before the barricade was destroyed. Also, since the two different-sized donors affected the barricade similarly at essentially the same K-factor distance, this may provide a means for locating barricades for even larger stacks.

Barricade C in Phase III demonstrated a response phenomenon different from the other barricades. At about 2 milliseconds before the airblast arrived at the face of the barricade, the horizontal accelerometer located at the structural centroid indicated a small amplitude motion. Since the response to the airblast indicated a very rigid structure, the early oscillations were attributed to the rigid structure response to the impingement of primary fragments (pieces of bomb casing).

For Phases I and II, most of the fragments (all primary fragments) collected were in the 0- to 0.25-pound weight class and about 90 percent of these were found on the first two fragmentation areas in each direction. Originally, the AFIAS C2 test data collection requirements stated that the only fragments of significance were those weighing 1 pound or more. In reviewing tables VI and VII it can be seen that very few fragments, compared with the total number collected, were found which met this criteria.

The donor bombs were positioned with the noses toward the W fragmentation areas and the sides toward the S fragmentation areas. These areas, which were centered from the donor, should have given good representative samples of fragments emanating from the detonation. Therefore, at distances representing barricaded intraline (575 feet) and public highway (1890 feet), the majority of the fragments were small and were projected over the barricade rather than through it. Also, these small fragments probably would not cause as much damage to a structure at the above-stated distances as the airblast or shock wave resulting from a 250,000-pound detonation.

The height of barricades for the BIG PAPA tests was based on the "2-degree" theory applied across the approximately 30-foot wide bomb stacks. This theory, proposed by the Explosive Safety Branch of the Directorate of Aerospace Safety (AFIAS-G2), Hq USAF, states that a straight line drawn from the far edge of the top of a bomb at a 2° angle above the horizontal must at least pass below the 3-foot wide crest of the standard earth barricade. This is considered minimum, and where feasible, a 5° angle should be used. This rule appeared to be sound since even though the barricade used in the BIG PAPA test did not meet this requirement along the 40-foot length of the storage pad, as shown in figure 64, very few fragments weighing 1 pound or more were found in the fragmentation survey areas of Phases I and II. However, as shown in figure 65, this "2-degree" theory was met across the 30-foot width of the pad. It can be safely concluded, therefore, that if this rule were maintained, no greater fragment density than occurred in Phases I and II would be experienced.

In Phase III, most of the primary fragments were within the 0- to 0.25-pound weight range. A significant difference was noted between the fragment distribution along two fragmentation survey lines over the barricades and the two fragmentation survey lines between the barricades. About 91 percent of this size fragments, found along lines E and W (over barricades), were recovered from the first two survey areas. The third survey areas on lines E and W produced less than 1 percent while corresponding areas on lines N and S produced about 22 percent.

The fragmentation survey for secondary fragments (barricade components) for Phase III was performed primarily to recover parts of the four metal-bin barricades (B, D, E, and F). As observed in tables XI through XVIII, most of

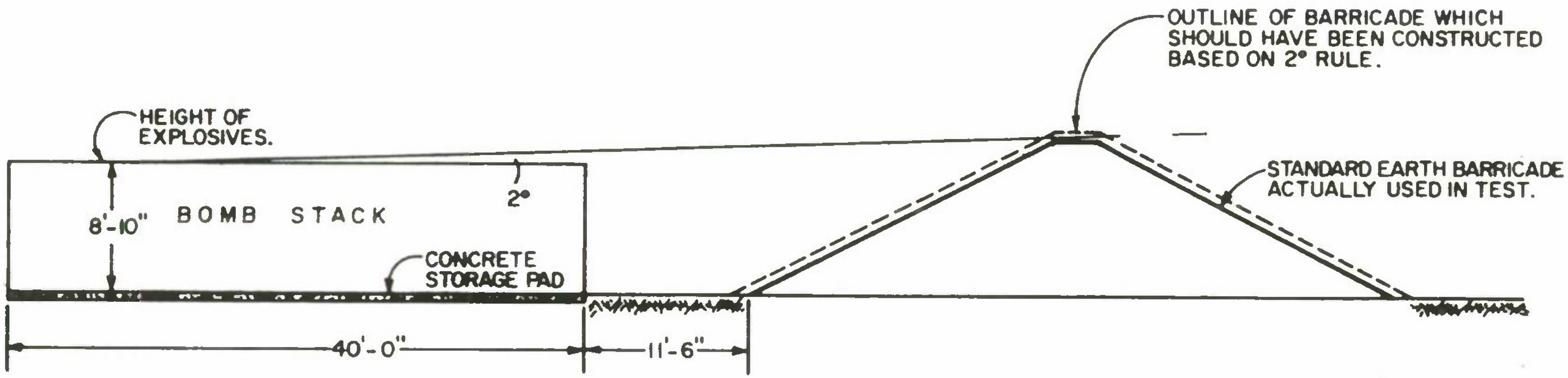


Figure 64. Comparison of Actual Barricade Height Used in Test and That Required by 2-Degree Theory for 40-Foot Long Bomb Stack

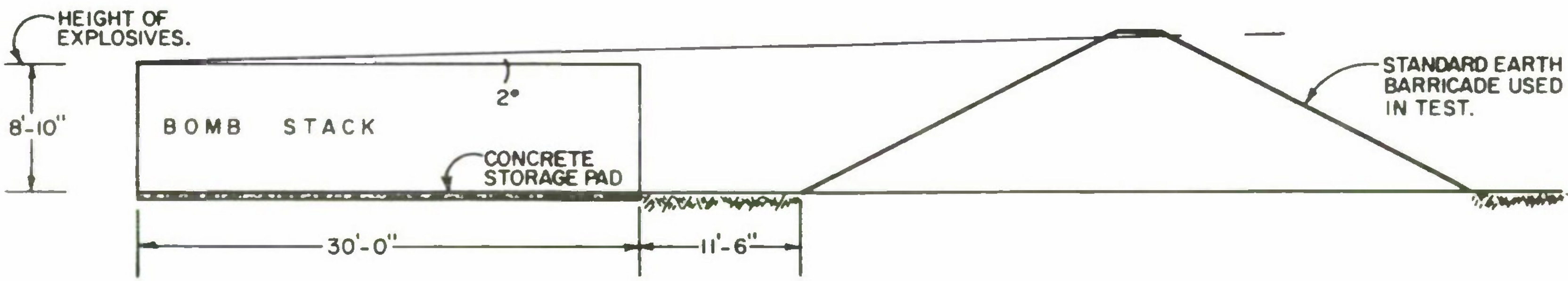


Figure 65. Barricade Height Required by 2-Degree Theory for 30-Foot Wide Bomb Stack

the secondary fragments were very small. The significant fragments, weighing 1 pound or more, all came from either Barricades B or D. Fragmentation areas 1W and 2W showed that, except for one fragment, only very small secondary fragments (less than 0.2 pound) were found. Most of these fragments came from Barricade F with a few from Barricade B. No secondary fragments such as stringers, wide-flange bracing members, columns, girts, or other very large members were recovered from the fragmentation areas. However, these very large members were spread over the test area as far out as 1000 feet from the center of the donor.

No secondary fragments were found on any of the remaining fragmentation survey areas past the second area (approximately 800 feet from the donor). From a general survey of the entire area out to approximately 1000 feet, it appeared that the use of 12WF27 steel beams as barricade bracing would be hazardous in an explosives storage area.

It appears from a review of the results that, if a metal-bin barricade is desired, one which contains a minimum number of small parts should be selected (Barricades E and F). Barricades whose structural components consist of clip angles, bolts, nuts, or other small parts would not seem to be desirable for storage for large quantities of explosives because of their ability to produce many significant secondary fragments (Barricades B and D).

The average compressive strength of the foam concrete was approximately 360 percent higher than the design (160 psi in 9 days). One reason for these excessive strengths could be attributed to the portable batching equipment used by the contractor to proportion the ingredients. The equipment was calibrated to batch large weights of ingredients to the nearest 100 pounds. In addition, the equipment was constantly in need of minor repairs. The unhardened density, taken in the field during pouring, ranged from about 42 to 58 pounds per cubic foot. The field specimens reported were selected for testing on the basis of their unhardened densities of approximately 48 pounds per cubic foot. Another reason for the high strength could have been the rapid curing condition of the foam concrete in the field. This excessive strength could have affected the fragment-catching ability of the foam concrete.

The crater data indicated two significant results. First, the shape of the crater was influenced by the arrangement of the explosives in the donor, and secondly, a rebound mound (or central peak) occurred in all three craters

surveyed. The craters resulting from Phases I and II were quite steep and the deep portion was rather small in diameter compared to the relatively shallow but wide crater of Phase III. This difference in crater geometry could conceivably be related to the difference in bomb stack geometry of Phases I and II as compared to that of Phase III and to the fact that the ground water table had risen considerably at the time of the Phase III test.

Another aspect of the crater which was noted was the marked increase in apparent-crater rim height over the area of intersection of two standard earth barricades. Figures 31 and 32 show the sections taken over these areas for Phase I. The reason for this height difference was assumed to be that the energy dissipated in the greater amount of soil concentrated at these intersections.

SECTION VII

CONCLUSIONS

All objectives of the BIG PAPA test were met in the four test phases. These included (1) determining minimum barricaded inter-stack distances; (2) validating the 100,000-pound per cell modular concept; (3) determining optimum barricade materials and geometry; (4) studying the effects of detonating a single bomb within a stack; and (5) acquiring airblast and ground-shock data.

The conclusions reached from this test series were

a. A substantial reduction can be made in the current Department of Defense (DOD) barricaded aboveground intermagazine quantity-distance criteria for mass-detonating explosives in open storage (revetments without structures that would burn or create heavy falling weights or damaging secondary fragments).

b. Bombs located at K = 1.1, or less, from the donor explosions will be covered with earth and unavailable for use until extensive uncovering operations are completed. Bombs at K = 2.5 separations will be readily accessible.

c. The minimum barricaded distance between single stacks of mass-detonating explosives stored in adjacent cells of a module could be based on a K factor of 1.1 with a high degree of confidence since six stacks, located at distances of K = 1.1 or less (four at 1.1 and one each at 0.9 and 0.8), were tested without causing any sympathetic simultaneous or delayed detonations. However, some possibility of nonsimultaneous propagation exists under some circumstances. Dunnage flammability and some possibility of damaging fragments escaping over the barricade are a few of the factors influencing probabilities in this connection.

d. The modular concept, developed by the Air Force Special Study Group and approved for use in combat zones, is sound for large-quantity munitions storage.

e. Since no sympathetic simultaneous or delayed detonations occurred within the test modules, the spacing between modules could be based on a K factor of 2.5 as related to the net weight of explosives in one cell rather than the 2.5 based upon the entire module as the AFSSG recommendation required.

f. The AFSSG recommendation of 100,000 pounds per cell can be increased to 250,000 pounds provided that the spacing corresponding to a K factor of 1.1 is maintained.

g. Since no sympathetic simultaneous or delayed detonations occurred, the number of cells per module (five recommended by the AFSSG) may be considered arbitrary.

h. The vertical acceleration delivered to a bomb stack resting on the natural ground surface is about twice the magnitude of one standing on a concrete storage pad.

i. The frontal air pressure is consistently higher than the ground surface pressure at any given distance out from the detonation.

j. The standard earth barricade does, in fact, affect the airblast in the immediate vicinity of the barricade, but the disturbance dissipated rapidly as the blast front moved out from the detonation. The pressure at a given point on the ground beyond the toe of the barricade was the same as to be expected where no barricades are employed.

k. Since very few fragments of significance were found out to the barricaded highway/railway distance, most damage to structures would probably result from airblast effects.

l. The Air Force "2-degree" theory for proper barricade height is sound.

m. The standard earth barricade provides excellent fragmentation protection for adjacent bomb stacks stored within a module as in Phases I and II.

n. Cell-to-cell propagation purely by airblast probably would not occur.

o. Metal-bin barricades having many small parts should not be considered for the storage of large quantities of high explosives because of the production of secondary fragments (barricade components). The secondary fragments which had sufficient mass would be hazardous in an explosive storage area.

p. The use of steel beams or piling as an anchoring device for the metal-bin barricades will create hazards in an explosive storage area in the event of an explosion.

q. Foam concrete as a fragment-catching mechanism to obtain energy data did not function as designed since no fragment penetrations were detected in any of the 10 acceptors. However, the crater that enveloped the front faces of the acceptors precluded analysis of that portion.

r. Based on acceleration data, the standard earth barricade remained in position longer and thus performed the fragment-catching function longer than any of the other five barricades tested.

s. The "high-order" detonation of a single bomb with current fill (tritonal or equal) within a stack can be expected to cause the "simultaneous detonation" (practically instantaneous) of all bombs in the stack.

t. Stacks of bombs spaced at a K-factor distance of 1.1 would require considerable recovery effort if one of the stacks detonated, whereas stacks spaced at a K-factor distance of 2.5 would require very little recovery effort.

SECTION VIII

RECOMMENDATIONS

Based on the findings of this research effort, the following recommendations are submitted:

a. Consideration should be given to spacing between the nearest stacks of explosives in adjacent modules--a computed distance using a K factor based on the total net weight of explosives in the largest single stack rather than the total of all cells in the module.

b. Consideration should be given to increasing the allowable quantity of explosives per cell of a module from 100,000 to 250,000 pounds (net weight of explosives) while maintaining a distance corresponding to a K factor of 1.1 between stacks within the module.

c. Consideration should be given to increasing the five-cell maximum presently established for individual modules. As previously indicated, the tests verified the modular concept but did not establish a limit on the number of cells.

d. All large quantities of high explosives should be stored on reinforced-concrete pads.

e. The "2-degree" theory should be established as a rule to determine the height of barricades for munitions storage.

f. Actual bomb stacks in true storage configuration should be used as acceptors in the event of any future testing of the relative merits of various types of barricades and barricade materials.

g. Foamed concrete or similar materials should be used as acceptors to simulate actual bomb stacks only when fragment penetration and energy data are required.

h. In any future barricade effectiveness testing, attention should be focused only on barricades which will not produce undesirable secondary fragments, and no steel beams or pilings should be used as bracing or as anchors inside of the barricades.

i. Electronic instrumentation should be included in all future full-scale field tests.

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13. ABSTRACT (Distribution Limitation Statement No. 4)

In July 1966, the Chief of Staff, USAF, was informed of the critical shortage of munitions storage at air bases in Southeast Asia (SEA). In September 1966, a special Air Force Ad Hoc Study Group was convened at the Armed Services Explosives Safety Board in Washington, DC, to determine if existing munitions storage quantity-distance criteria for barricaded munitions (bombs) could be reduced. The Ad Hoc Study Group recommended a storage configuration incorporating standard earth barricades and reduced quantity-distance criteria which would prevent the propagation of sympathetic simultaneous detonations from one bomb stack to another. The study group also recommended a test program to validate the newly recommended criteria. A four-phase test program was developed and executed as described in detail in this report. Full-scale barricaded bomb stacks were used as donors. Both full-scale and scaled acceptors were used. Donor stacks were detonated to discover if blast, thermal effects, or fragment impingement could produce sympathetic simultaneous detonations in the acceptor stacks. Total explosive weight, distances between stacks of bombs, and types and heights of protective revetments were the basic parameters investigated. No sympathetic simultaneous detonations were propagated from a donor stack to any acceptor in any of the tests. Tests of earth-filled, metal-bin barricades resulted in the conclusion that such barricades should not be used for storage of large quantities of bombs at revised quantity-distance criteria distances.

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Overpressure						
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